

FINAL REPORT

DEVELOPMENT AND EXTENSION OF PRECISION FARMING
TECHNIQUES FOR SASKATCHEWAN PRODUCERS

19960130

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Prepared by: University of Saskatchewan



Canada¹

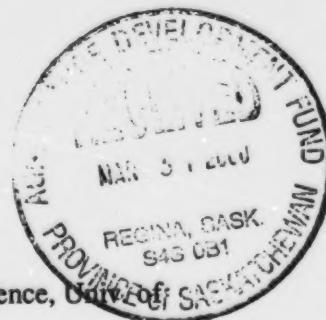
Saskatchewan



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Project Name: Development and Extension of Precision Farming Techniques for Saskatchewan Producers

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(a) SUMMARY

The objective of this study was to increase profitability and sustainability of Saskatchewan farms by developing and extending appropriate precision farming technologies. Landscape-scale experiments were conducted at four sites with variable topography during a three-year period to examine the response of spring wheat to variable rate fertilizer (N and P) and seeding rate treatments. Response to fertilizer inputs was limited in upper slope positions due to moisture limitations. The greatest potential for increased yields occurred in lower slope positions; however, these positions also were subject to yield losses due to adverse growing conditions including flooding, and weed and disease pressure.

(b) TECHNICAL REPORT

BACKGROUND AND OBJECTIVES:

This AFIF project was designed to assist in the successful adoption of precision farming by Saskatchewan producers. The overall objective of the project was to increase the profitability of Saskatchewan producers and the sustainability of their farms through the development and extension of precision farming technologies that work for Saskatchewan conditions. The specific objectives were:

1. To develop the agronomic information required for successful adoption of precision farming.
2. To evaluate the suitability of precision farming equipment currently being purchased by Saskatchewan producers.
3. To determine the economics of precision farming systems in Saskatchewan.
4. To develop and deliver the extension materials required for Saskatchewan producers to make an informed decision about the suitability of precision farming for their specific operation.

PROJECT ACTIVITIES:

Landscape-Scale Research 1997-1999

Materials and Methods

Climate

Climatic conditions during the growing season for all three years were assessed using a Campbell Scientific CR-10X Data logger located at each of the sites. The climate stations were located on level landscape positions, and the minimum temperatures recorded in periods of frost likely underestimated the actual minimum temperatures

achieved in the lower slope positions at the research sites. The rainfall values were recorded as millimeters of precipitation, and the temperature values were used to calculate Growing Degree Days where:

$$\text{Growing Degree Days} = ((\text{Daily Maximum Temperature} + \text{Daily Minimum Temperature})/2) - 5$$

In addition, the occurrence of significant events such as the occurrence of frost and rainfall events greater than 20 mm (i.e., those that may have produced significant runoff events) were tabulated separately.

Field Operations and Sampling

Site Selection

Field-scale plots were selected at four geographically distinct areas of the province in order to provide a cross-section of the agricultural soils of Saskatchewan. Each of the four sites was associated with a collaborative research agency (Table M1). At each site approximately 12 ha of land was set aside for the project, 4 ha of which were used in each year of the study. In each year the remainder of the plot was treated in the same manner as the adjacent commercial field. In the fall of 1996, at each of the sites, both topographical and soil surveys were carried out to ensure that soil properties and topographic characteristics were similar across the entire 12 ha area.

Table M1: Research sites and collaborating partners.

Site	Collaborator	Soil Zone		Parent Material
Swift Current	S.P.A.R.C. ¹	Brown	Dryland	Glacial Till
Outlook	C.S.I.D.C.	Dark Brown	Irrigated	Lacustrine
Watrous	S.W.P.	Dark Brown	Dryland	Glacial Till
St. Louis	A.A.F.C.	Black	Dryland	Lacustrine
S.P.A.R.C.:	Semi-Arid Prairie Agriculture Research Centre; Swift Current, SK, contact person: Dr. Brian McConkey, research scientist.			
C.S.I.D.C.:	Canada-Saskatchewan Irrigation Diversification Corporation, Outlook, SK., contact person; Mr. Terry Hogg, Centre Agronomist.			
S.W.P.	Saskatchewan Wheat Pool, Watrous, SK., contact person; Mr. Garry Hnatowich, Research Agronomist			
A.A.F.C.	Agriculture and Agri-Food Canada, Melfort, SK., contact person; Dr. Adrian Johnston, research scientist, currently at Potash & Phosphate Institute of Canada, Saskatoon, SK.			

Fertilizer Recommendations

In early spring of each year, at each site, 10-15 midslope samples were manually obtained, composited, and sent to Enviro-Test Laboratories for a standard soil test recommendations. The soil test recommendations were used to determine the rates of fertilizer input required for a given site (Table M2). These fertilizer rates are referred to as the 1X rate through the remainder of this document.

Table M2: Fertilizer recommendations (1X rate) at the AFIF sites over the three years of the experiment.

Site	N Recommendation (kg ha ⁻¹)			P ₂ O ₅ Recommendation (kg ha ⁻¹)		
	1997	1998	1999	1997	1998	1999
Swift Current	56	45	45	28	28	34
Outlook	112	112	112	28	28	39
Watrous	67	67	67	34	34	28
CLC	78	56	67	34	34	22

Delineation of Management Units

In the fall of 1996 a topographical survey of each site was completed and Digital Elevation Models (DEM's) were developed from the surveys. As well, ground control points were taken from each site and the surrounding area using a Garmin Survey II GPS unit. These ground control points were used to geo-rectify the aerial photographs used in the delineation of the management units. The topographical survey was used to classify each of the cells of the DEM into one of four landform element complexes: shoulders, backslopes, footslopes and level depressional complexes. The landform classification was further generalized into three management units by combining the footslope and level depressional complexes into one management unit, referred to as the lower management unit. These topographically defined classes were used to assess the validity of the delineation of management units based on the digital number classification (Pennock et al., 1994).

Existing aerial photographs for each site were scanned into the computer and imported into a VGA-Erdas image analysis system. The scanned images were then geo-rectified using the ground control points taken in the GPS survey. The images for each quarter-section were stored as gray tone images. The pixel size used initially was 3m by 3m, and each pixel also contained the appropriate digital number indicating the specific gray tone the pixel fell into. Digital numbers range from 1 (black) to 255 (white).

The digital number range for the Swift Current, Outlook, and Watrous sites initially was split into three classes: upper slopes, midslopes, and lower slopes & depressions (referred to as lower slopes). At the CLC site the digital number range was only split into two classes, upper slope and lower slope, due to the lack of a well

expressed midslope management unit. These classes formed the main management units at the sites, and are hereafter referred to as management units. Generally the digital numbers decreased from upper slope units to lower slope units. The management units were also compared with the topographically defined units and here a more clear association occurred. The management units defined from the aerial photographs were used to select the units for sampling in the three years of the study. In some cases the midslopes units were not well expressed on the management unit maps and in these cases the midslopes were arbitrarily placed between the upper and lower slope units.

Experimental Design

The recommended soil test levels were used to develop fractional rates of the recommended values for N and P at the sites. The N treatments (0, 0.5, 1, 1.5 and 2X the soil test rate) and P treatments (0, 0.5, and 1X the soil test rate) were replicated six times. Treatments were randomized in each block (or replicate) and each block of treatments spanned the management units at each site. The layout of the main treatments is shown schematically in Figure M1.

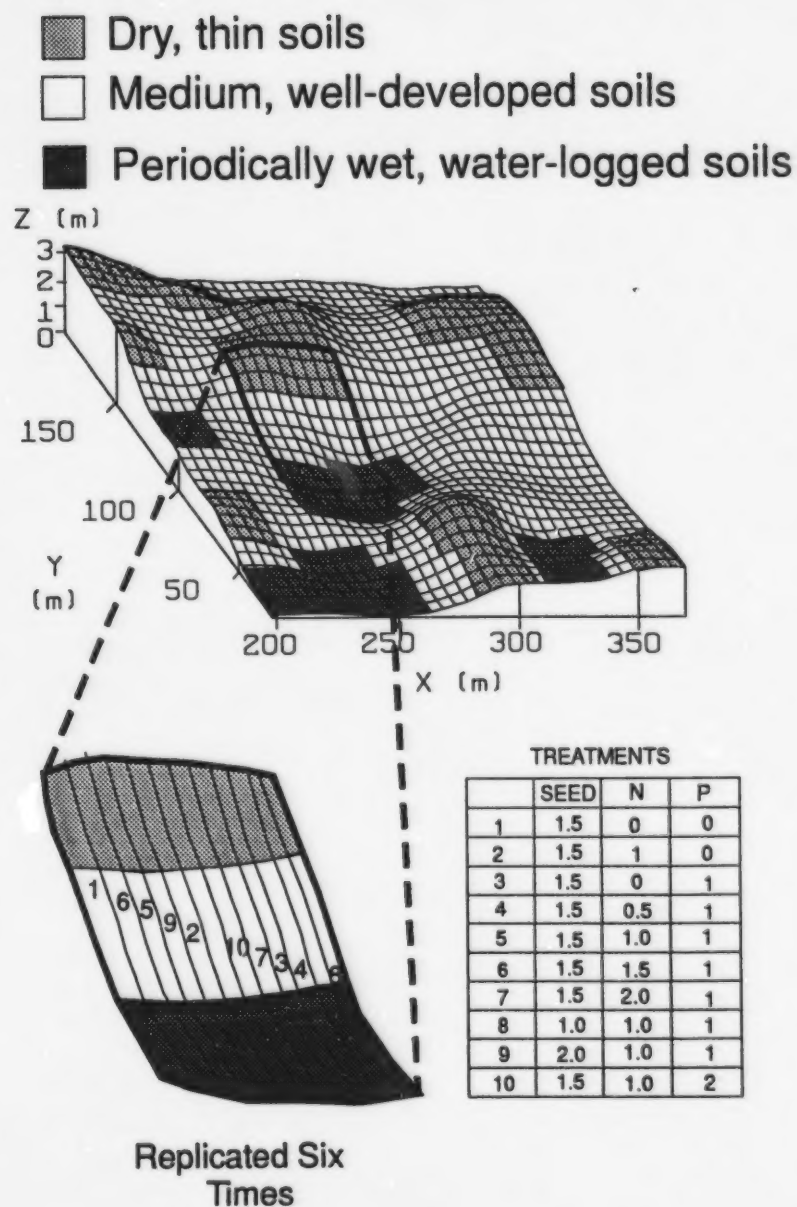


Figure M1: Hypothetical representation of experimental design used at the AFIF sites.

Seeding, Weed control, and Harvest

The collaborating partner undertook seeding and harvest, at each site. The type of seeder used at each site varied due to the availability of equipment (Table M3). Seeding dates varied slightly depending on the year and are summarized in Tables M3.

Table M3: Seeding equipment at the AFIF sites.

Site	Width (m)	Spacing (cm)	Brand	Type
Swift Current	2.00	20	Versatile Noble	Hoe Drill
Outlook	1.50	25	Custom made	Hoe/Disc
Watrous	2.13	30	Morris (modified)	Disc
CLC	2.00	20	Edwards (modified)	Hoe-Drill

The plots were harvested following biomass sampling. Biomass sampling, for the determination of harvest index, was accomplished by manually obtaining 1m² samples with a plant sampling frame and sickle. Biomass samples were bagged in large cloth sacks and allowed to dry to an equilibrated moisture content at 30°C prior to biomass determination. Biomass weights were subsequently converted to a per hectare basis. Ten metre long harvest strips were also delineated at the same time as the biomass determinations with a self-propelled sickle bar mower. The plots were subsequently harvested with a small plot combine. Grain yield and grain moisture content were determined, by the collaborating partners, on samples obtained with small plot combines. Grain yield and protein content were both standardized to 14.5% moisture content using the following formula:

$$\text{grain weight (14.5\% moisture)} = \text{measured yield (kg} \cdot \text{ha}^{-1}) \times \left(\frac{1 - (\theta_{\text{grain}}/100)}{1 - 0.145} \right)$$

The collaborating partners carried out weed control, both the assessment of weed pressure and the initiation of the spraying programs. Type of chemical, chemical rates, and spray dates are summarized in Table M4.

Table M4: Seeding, harvest, and herbicide history at each of the AFIF sites.

Year	Pre-seeding burn off		Seeding		In crop Herbicide Application		Harvest
	Product (Rate)*	Date	Variety	Date	Product (Rate)*	Date	Date
<i>Swift Current</i>							
1997	Roundup	Late April	AC barrie	May 1	-Achieve Extra Gold	<i>Mid June</i>	August 26
1998	Roundup	Late April	AC barrie	May 6	-Achieve Extra Gold	<i>Mid June</i>	August 19
1999	Roundup	Late April	AC barrie	May 19	-Achieve Extra Gold	June 17	September 16
<i>Outlook</i>							
1997	Roundup	May 12	AC barrie	May 5	-Laser DF	June 8	September 8
1998	Roundup	N/A	AC barrie	May 13	-Puma -Buctril M	June 11	September 1
1999	Roundup	N/A	AC barrie	May 19	-Puma Super -Refine Extra	June 14	September 16
<i>Watrous</i>							
1997	N/A	N/A	AC barrie	May 6	Gold -MCPA Amine	N/A	August 14
1998	N/A	N/A	AC barrie	May 8	-Attain -Horizon	June 5 June 23	September 3
1999	Roundup	June 2	AC barrie	June 7	-Achieve Extra Gold	June 27	October 4
<i>CLC</i>							
1997	Roundup	May 12	AC barrie	May 31	-Assert (0.46 L/ac) -Curtil	June 26	September 11
1998	Roundup	May 13	AC barrie	May 19	-Refine Extra -Horizon	June 15 June 23	September 4
1999	Roundup	May 21	AC barrie	May 31	-Attain -Horizon (0.1 L/ac)	June 25	September 16

*chemical applied at manufacturers recommended rate unless specified otherwise.

Soil Sampling

Prior to seeding and following harvest, soil cores were taken in Treatments 3, 5, and 7 from each of the management units across all six replicates. These samples were obtained with a truck-mounted hydraulic soil sampler to a depth of 90 cm, incremented as follows: 0-15 cm, 15-30 cm, 30-60 cm, and 60-90 cm. At 25, 50, and 75 days after planting (D.A.P.) soil samples (0-30 cm) were manually obtained at the same points in the field as the spring soil samples.

Soil Analysis

Mineral N was determined on samples collected from Treatment 3 to a depth of 60 cm, in 30 cm increments. In 1997 and 1998, mineral N content (i.e., ammonium and nitrate) was determined by a colorimetric method. After the addition of 200 ml of 2N KCl, to 50 g of fresh soil, the samples were shaken for 1 hr. These samples were subsequently filtered through Whatman #2 qualitative filter paper and analyzed with a Technicon Autoanalyzer II System (Labtronics Inc., Tarrytown, NY, USA). Mineral N was considered to be the sum of ammonium and nitrogen. The ammonium levels noted in the first two years of the experiment were negligible, thus, in 1999, only nitrate was measured. These determinations, in 1999, were carried out by Enviro-Test Laboratories in accordance to their standard laboratory practices.

Soil organic carbon was determined on samples collected from Treatment 3 to 60 cm, incremented as follows: 0-15 cm, 15-30 cm, and 30-60 cm. Soil organic carbon was measured using a Leco model CR 12 Carbon Determinator. Two-tenths of a gram of soil

was weighed out and combusted at 840°C; only organic carbon, rather than total carbon, is combusted at this temperature. Percent organic matter was converted to a mass/area basis by multiplying values obtained by both bulk density and sampling increment.

Bulk density (oven dry basis) was calculated using the core method, on core samples obtained both in the spring and fall. Bulk density was considered to be the average of both measurements. Gravimetric soil moisture was determined by oven drying approximately 20 g of soil at 105°C for 48 hrs. These values were converted to a volumetric basis by multiplying by bulk density. Moisture content at permanent wilting point was determined using the pressure plate technique. Approximately 30-40 g of finely ground air dry soil was brought to saturation over a 48 hr period, the samples were then subjected to a pressure equivalent of 15 bar suction for 48 hrs. The samples were weighed immediately after removal from the pressure plate, oven dried for 48 hrs at 105°C, and weighed again. The volumetric moisture content was calculated and considered to be the moisture content at permanent wilting point.

Fertilizer response functions and economic analysis

Separate fertilizer response curves were developed specific to each of the three management units for each growing season. The average yield of six replicates for each fertilizer treatment was plotted against fertilizer rate. A quadratic function was subsequently fitted to each yield vs. fertilizer rate plot. Quadratic fertilizer response equations are found to be a satisfactory representation of crop response to a given nutrient. In general increased fertilizer application rates result in increased crop yield.

However, increasing fertilizer rates results in diminishing increments in yield to some maximum yield, any additional fertilizer results in decreased crop yield (Figure M2).

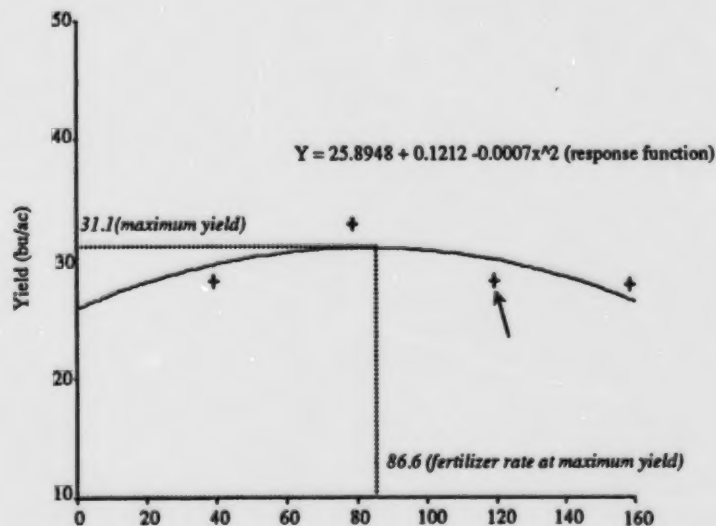


Figure M2: Hypothetical fertilizer response curve.

In some instances where fertilizer rates were not sufficient to result in maximum yields the fertilizer response curves were approximated as being linear. The economically optimum N-fertilizer rate, or economic optima, was derived at the end of each growing season for each management unit. The economic maximum was determined by applying simple differential calculus to each of the acquired response functions. The fertilizer rate resulting in the maximum yield for each management unit was determined by setting the first derivative of the yield function equal to zero. Maximum yield differs from the economic optima due to the relationship between input costs and the value of the crop. For this reason, the economic optima is determined by considering the price ratio between the unit cost of inputs, namely n fertilizer, and the unit value of yield. The price ratio is defined as the cost of the input divided by the value

of the crop. The economic optimum is thus determined by setting the first derivative of the response function equal to the price ratio. Since the price ratio is a positive value, the economic optimum is always to the left of the yield maximum on the fertilizer response curve. The fertilizer rate coinciding with maximum yield converges with the fertilizer rate coinciding with the economic optima as the price ratio approaches zero, that is, as either the commodity price rises or the price of nitrogen falls.

Statistical Analysis

The four sites used in the study were not combined for the analysis. At the outset of the study the sites were chosen to reflect differences in the major agricultural landscapes of Saskatchewan and it was not assumed that consistent responses would be observed among the sites. Moreover the sites were such that direct comparability in conditions and treatments was not possible – for example, only the Outlook site was irrigated, and only two management units (upper and lower) occurred at the CLC site due to the surface forms present. Hence the analysis (and the text) is presented on a per-site basis.

The results were analyzed using Analysis of Variance techniques. The statistical model includes sources of variation due to year, landscape position, treatment (N, P, or seeding rate), replication, and their interactions. A mixed model was used, with year and replication regarded as random factors and treatment and landscape position as fixed factors. The error term for the model includes the interaction between replication and the remaining factors.

In 1999 at the Swift Current site, the research site overlapped into what proved to be (after historical research was completed) two fields with different cultivation histories. This caused three of the blocks to show results that were uncharacteristic of the previous two years of the study. The analysis for this site alone only used three replicates for the ANOVA.

The yield functions were analyzed for their economic implications even if a statistical difference between treatments was not indicated by the overall ANOVA results. The experiment from the outset was structured to allow the response of the crop to the fractional treatments to be assessed and hence this analysis was performed for the data set.

A point of discussion in these landscape-scale agronomic designs is whether the landform positions at a site represent true replication or pseudo-replication of that factor. We would argue that the six sets of management units at each site represent true replication because the management units chosen at each site were selected such that they were spatially independent. By this we mean that there was no obvious surface flow paths linking the landform segments between the replicates and hence the response of yield in a given block was unaffected by the response in an adjacent block of treatments.

Results:

Watrous

The Watrous site was located at NE12-31-26-W2 on land owned by the Mr. B. Penrose and Mr. D. Penrose. The site is mapped as the Weyburn 15 map unit, which are Dark Brown soils formed in loamy glacial till. All seeding, spraying, and harvest operations at this site were carried out by staff of the Saskatchewan Wheat Pool under the supervision of Mr. G. Hnatowich. This work formed part of the SWP's in-kind contribution to this study.

The distribution of soils at the Watrous site is very typical of hummocky till landscapes throughout the agricultural zone of the province (Table W1). The upper slopes are dominated by thin Orthic Regosolic soils that lack an organically enriched topsoil layer. The dominant soil of the midslopes is the Orthic Chernozem, which has an A horizon greater than 10 cm thick and a B horizon that has experienced the loss of calcium carbonate. These soils are also typical of the lower slopes, but significant numbers of well developed Eluviated Chernozemic soils and periodically water-saturated Gleysolic soil also occur in the lower slopes.

The differences in soil distribution are reflected in the differences in soil organic carbon (SOC) associated with the management units (Table W2). The storage of SOC is lowest in the upper slope management units, which have the thin soils discussed above. SOC in the midslope units is marginally higher than the upper slope units, but the lower slope units have substantially greater amounts of SOC storage. SOC is used as a measure of soil organic matter, which is a fundamental control on many soil fertility and physical properties. Generally we would expect that the higher the SOC content of the soil, the

more productive it should be (all other factors remaining equal). Hence both the soil distribution and the SOC distribution in this landscape would indicate an inherent productivity increase from upper through to lower slope soils.

Growing season precipitation was below the thirty-year average for all three years of the study (Table W3). The precipitation events were relatively evenly distributed over the growing season in 1997 and 1999. In 1998, two intense rainfalls occurred 42 and 49 days after planting (DAP). Growing degree days were above the 30-year-average for 1997 and 1998, and below average for 1999. Seeding was late in 1998 due to very wet field conditions. Sharp frosts were experienced immediately after seeding in 1997 and 1998, whereas the late seeded crop in 1999 experienced 11 frost events prior to harvest.

Spring moisture levels overall were highest in 1999 (as reflected in the late seeding date) and were lowest in 1998 (Table W4). In 1998 all three management units were below permanent wilting point at the time of seeding and no significant differences existed between the three management units. In 1997 both the upper and midslope units had very poor moisture conditions at the time of seeding, whereas the lower slope unit had fair moisture conditions. In 1999 the moisture conditions increased from the upper through to the lower slope units, but all units had moisture levels well above the three-year average.

Regardless of the spring moisture conditions and growing season precipitation levels, water loss by evapotranspiration had fully depleted the soil moisture reserves by the time of harvest. The very dry conditions after harvest highlight the role of snowmelt and early spring precipitation in replenishing the soil moisture for the growing season.

The plant available N levels at seeding also increased over the three years of the study (Table W5). The spring N levels in all three management units were very high in 1999, averaging at 76.2 kg ha⁻¹ to 60 cm. The very high spring N levels reflect the late seeding date – mineralization of soil N had been occurring for over one month before seeding occurred and hence a large reservoir of N was available to the crop. The clearest management unit trend occurred in 1997, where the spring N levels in the lower slopes were over twice that on the upper slope units. The range between units in 1998 was very small.

Nitrogen Treatments

The overall Analysis of Variance (ANOVA) for the N treatments shows the very strong annual variations in yield (Table W6). Both year and the interactions of year with management unit (LP) and N treatment were significant. The lack of a significant term for treatments indicates that there was not a consistent yield response across the three years of the study for yield. For grain protein only the year and year x treatment interactions are highly significant, indicating that (unlike yield) the management units do not have a significant effect on grain protein.

The strong annual variations in both yield and protein are closely related to the spring moisture conditions (Table W7). Yields were similar in 1997 and 1999 but were significantly lower in the driest year, 1998. Protein contents in 1997 and 1998 were inversely related to yields – high yields in 1997 resulted in lower protein contents, the reverse occurred in 1998. This relationship did not hold for 1999 – both yield and protein were low. We believe that this was caused by the cooler temperatures experienced in

1999 as reflected in the below average growing degree days discussed previously. The cooler temperatures caused considerable biomass production relative to the other two years. The average harvest index (mass of grain/mass of straw) across N treatments was 0.31 in 1997, 0.37 in 1998, but only 0.22 in 1999 – hence considerably more biomass relative to grain yield was produced in 1999 relative to the previous two years.

There was a strong management unit effect across the N treatments for yield but not for protein (Table W8). Averaged across the three years of the study, yields showed a very regular 300 kg ha^{-1} increase from upper through midslope to lower slope units. Hence the perception that slope position influences yields is borne out by this study. The same was not true for protein – there was no difference between the average protein levels of the management units across the years of the study.

The management unit effect on yield occurred in all three years of the study (Table W9); however the absolute differences among the management units differed among the three years. For example, the difference between the upper and lower slope units was 884 kg ha^{-1} in the driest year (1998) but only 347 kg ha^{-1} in the wettest year, 1999. Hence while the rank of the units for yield was consistently upper<midslope<lower, the absolute differences were dependent on the year. No management unit effect on protein occurred in any year of the study (Table W10).

The strong year by treatment interaction indicates that there was not a consistent yield or protein response to the five N treatments over the three years of the study. This can be further illustrated by examining the yield functions (Figures W1 to W3) and associated values (Tables W11 and W12). In 1997 the yield functions for the midslope and upper slope were very similar and show a distinct curvilinear form with a pronounced

yield plateau. The lower slopes exhibited a linear relationship between yield and N treatments. Note that the inherent productivity (i.e., with 0N fertilizer added) also indicated an overlap between the upper and midslopes and a clear separation from the lower slope units. In 1998 the yield functions again clearly showed a separation among the management units at the 0N rate but there was very little response to the higher rates of N fertilizer addition, especially for the upper slope units. We would argue that the very dry conditions at the time of seeding and for the first 40 days of the growth period greatly limited the ability of the crop to utilize the added N fertilizer. In 1999 there was little separation of the growth curves at the 0N rate, and they essentially converged at the 2XN rate. The midslope and lower slope curves are flat and only the upper slope curve showed the characteristic yield plateau. In 1999 the spring soil moisture conditions at seeding were high (relative to the other three years of the study) in all management units but the cool temperatures limited the ability of the crop to produce higher yields. Instead, the biomass production was high, as seen in the low harvest indices discussed earlier.

The great year-to-year variations in yield response to the N treatments caused a great range in the optimum economic scenarios based on a VRF program (Table W13). In 1997, the economic optimum scenario was basically the 1XN rate for upper and midslope units and the full 2XN rate for the lower slopes. This would return \$11 ha⁻¹ to the producer relative to a conventional whole-field 1X application. In the driest year, 1998, the economic optimum rates were below the 1X rate throughout the field. The economic optimum rate for upper slopes in this year was 0 kg ha⁻¹, which was the major contributor to the \$18 ha⁻¹ return in this year. In 1999 the pure economic analysis would suggest adding the 2X rate on the upper slope units. However this high rate of inputs only

resulted in a \$5 ha⁻¹ benefit over the 1X rate and this would be an unacceptable return for this rate of input for many (if not all) producers. The highest returns in 1999 occur by reducing the midslope inputs to 0N. Our recommendation on eliminating fertilizer applications in this landscape position is based purely on hindsight; we would not have been able to predict a lack of response to N prior to seeding. Moreover, the sustainability of withholding fertilizer applications in these positions would compromise their long-term fertility status.

The average three-year return based on the optimum economic scenario is \$15 ha⁻¹. This is based on perfect hindsight and moreover includes several 0N rates, which we would not recommend as an agronomic practice.

Phosphorus and Seeding Rate Treatments

Neither the phosphorus or the seeding rate treatments resulted in a significant treatment effect (Tables W14, W17). The yields for the phosphorus treatments showed a management unit effect, but this did not occur for protein or for either variable for the seeding rate treatments. The management unit effects have been discussed in detail above and will not be discussed further here.

Generally for the P treatments a yield response was achieved for the P increment between the 0P and 1XP rate for all management units in 1997 and 1998. The greatest yield increment was between these two rates for the upper slopes in 1997 (704 ha⁻¹). Generally the increase to the 2X rate marginally depressed yields below the value achieved at the 1X rate. In 1999 little response to any level of added P fertilizer occurred. There was a very limited response to protein to the higher P rates in any year of the study.

The seeding rate treatments in 1997 (Table W18) showed no differences across the treatments (although the usual management unit effect was seen). In 1998 and 1999 the same basic trend occurred – the yields increased marginally as the seed input increased, and this increase was greatest in the lower slope units. These differences were not, however, strong enough to give a consistent treatment effect.

Table W1: Distribution of soil subgroups in the management units. The subgroups are arrayed in approximate order from driest to wettest. These results are tabulated from the three years of the study.

Orders and Soil Subgroup	Upper Slope	Midslope	Lower Slope
<i>Regosolic</i>			
Orthic	46	18	1
<i>Chernozemic Dark Brown</i>			
Rego	2	7	8
Calcareous	5	3	1
Orthic	13	37	31
Eluviated		1	14
<i>Gleysolic</i>			
Rego Humic			6
Humic Luvic			5

Table W2: Mean soil organic carbon in the management units. These results are tabulated from the three years of the study.

Management Unit	Soil organic carbon. (Mg ha ⁻¹)
Upper	71.8 ^a
Mid	89.9 ^b
Lower	131.9 ^c
<i>Grand mean</i>	97.6

Table W3: Growing season climate statistics; precipitation, growing degree days, and significant events.

Site	Seeding Date	Seeding to 25DAP	26DAP to 50DAP	51DAP to 75DAP	76DAP to Harvest	Growing Season Precipitation	Growing Degree Days (base 5°C)
----- Precipitation (mm) -----							
1997	May 6	37.6	58.2	5.9	32.3	134.0 ¹	1337
1998	May 8	30.3	118.6	22.0	20.4	191.3	1401
1999	June 7	87.0	73.1	25.7	9.2	195.0	1237
30 year average ²						222.1	1270
Significant Events							
Date	Frost (Minimum Temperature C)			Precipitation Greater than 20mm			
1997	May 6	-0.5					
	May 8	-0.8					
	May 11	-0.5					
	May 12	-3.0					
	May 14	-4.1					
	May 15	-2.0					
	May 18	-1.9					
	May 19	-5.0					
1998	May 12	-0.6			June 19	63.5	
	May 13	-4.5			June 26	32.9	
	May 14	-1.0					
1999	September 13	-0.5			June 21	33.0	
	September 14	-1.2					
	September 19	-0.1					
	September 20	-0.1					
	September 27	-2.4					
	September 28	-1.3					
	September 30	-6.3					
	October 1	-9.6					
	October 2	-7.0					
	October 3	-7.2					
	October 4	-0.8					

¹Total Precipitation-Seeding to Harvest.

²30 year averages, May 1 – September 31, obtained from the nearest Environment Canada Meteorological Station.

Table W4: Plant available water; pre-seeding.

Landscape Position	1997	1998	1999	Across years
	----- <i>cm available water per 90 cm soil</i> -----			
Upper	-0.22 ^a	-2.02 ^a	3.04 ^a	0.17 ^a
Mid	-0.46 ^a	0.03 ^a	4.89 ^b	1.14 ^a
Lower	5.83 ^b	-0.67 ^a	5.72 ^b	4.03 ^b
Grand mean	1.71	-0.89	4.55	1.78

Table W5: Soil nitrate; pre-seeding.

Landscape Position	1997	1998	1999	Across years
	----- <i>Kg ha⁻¹ to 60 cm</i> -----			
Upper	17.5	43.8	71.1	32.2 ^a
Mid	24.5	41.8	77.5	36.1 ^a
Lower	45.1	48.1	80.0	49.9 ^b
Grand mean	29.0	44.6	76.2	39.4

Table W6: Analysis of variance for grain yield and protein for the N treatments.

Source	df	Grain yield	Grain protein
		----- <i>Mean squares</i> -----	
Years (Y)	2	25754059**	185.530**
Landscape position (LP)	2	10123736*	0.188
Y*LP	4	1075314**	0.689
Replications	5	944265**	1.074*
Treatment (T)	4	3015594	26.736
Y*T	8	867413**	15.863***
LP*T	8	113335	0.129
Y*LP*T	16	201799	0.284
Error	219	232724	0.390

*significance level: .05

**significance level: .01

***significance level: .001

Table W7: Mean grain yield and protein averaged across treatments and landscape position.

Year	Grain yield	Grain protein
	(kg ha ⁻¹)	(%)
1997	2312 ^a	12.2 ^a
1998	1316 ^b	14.0 ^b
1999	2165 ^a	11.1 ^c
<i>Grand mean</i>	1933	12.5

Table W8: Mean grain yield and protein averaged across years and treatments.

Year	Grain yield	Grain protein
	(kg ha ⁻¹)	(%)
Upper	1609 ^a	12.4 ^a
Mid	1913 ^b	12.4 ^a
Lower	2278 ^c	12.5 ^a
<i>Grand mean</i>	1933	12.5

Table W9: Mean spring grain yield averaged across N treatments.

Landscape Position	1997	1998	1999
	<i>Kg ha⁻¹</i>		
Upper	2018 ^a	837 ^a	1971 ^a
Mid	2121 ^a	1394 ^b	2206 ^b
Lower	2796 ^b	1721 ^c	2318 ^b
<i>Grand mean</i>	2312	1316	2165

Table W10: Mean spring grain protein averaged across N treatments.

Landscape Position	1997	1998	1999
	<i>%</i>		
Upper	12.0 ^a	14.1 ^a	11.2 ^a
Mid	12.2 ^a	14.0 ^a	11.1 ^a
Lower	12.5 ^a	13.9 ^a	11.2 ^a
<i>Grand mean</i>	12.2	14.0	11.1

Table W11: Effect of N fertilizer rate on grain yield across management units.

Landscape position	Grain Yield (Kg ha ⁻¹)				
	0N1P	0.5N1P	1N1P	1.5N1P	2N1P
-----1997-----					
Upper Slope	1164	2189	2345	2190	2202
Midslope	1454	2142	2341	2209	2461
Lower Slope	2155	2392	2991	2919	3523
Column Mean	1591	2241	2559	2439	2729
-----1998-----					
Upper Slope	834	990	927	788	645
Midslope	1138	1209	1857	1355	1366
Lower Slope	1578	1559	1942	1791	1735
Column mean	1186	1253	1575	1311	1249
-----1999-----					
Upper Slope	1584	1750	1935	2233	2355
Midslope	2051	1955	2194	2453	2377
Lower Slope	2015	2340	2317	2457	2459
Column Mean	1883	2015	2149	2381	2397

Table W12: Effect of N fertilizer rate on grain protein across management units.

Landscape position	Grain Protein (%)				
	0N1P	0.5N1P	1N1P	1.5N1P	2N1P
-----1997-----					
Upper Slope	9.5	11.0	12.5	13.4	13.9
Midslope	9.7	10.9	12.6	13.6	14.3
Lower Slope	10.2	11.6	12.7	13.9	14.0
Column Mean	9.8	11.1	12.6	13.6	14.0
-----1998-----					
Upper Slope	13.7	13.9	14.1	14.3	14.4
Midslope	13.5	14.0	14.0	14.6	13.8
Lower Slope	13.5	13.7	14.1	14.7	13.7
Column mean	13.6	13.9	14.1	14.5	14.0
-----1999-----					
Upper Slope	11.4	10.9	10.8	11.3	11.5
Midslope	11.5	10.8	10.8	11.1	11.5
Lower Slope	11.0	10.8	11.2	11.2	11.6
Column Mean	11.3	10.8	11.0	11.2	11.5

Table W13: Economic Optima Nitrogen Rates and Net Returns. Calculations assume N@\$0.587 kg⁻¹ and wheat@\$0.11043 kg⁻¹ for a price ratio of 5.3156.

Unit	N Rate at Economic Optima ----- Kg ha ⁻¹ -----	Yield at Economic Optima	Net Return at Economic Optima ----- \$ ha ⁻¹ -----	Minus Net Return at 1X Rate
----- 1997 -----				
Upper	70 (1.04X) ¹	2367.8	220.38	0.14
Mid	73 (1.09X)	2326.5	214.07	0.28
Lower	134 (2.00X)	3448.9	301.97	32.65
Entire Field ²				11.02
----- 1998 -----				
Upper	0 (0.00X)	856.8	94.61	39.45
Mid	46 (0.69X)	1491.8	137.74	4.03
Lower	19 (0.28X)	1639.9	169.94	9.81
Entire Field				17.76
----- 1999 -----				
Upper	134 (2.00X)	2374.2	183.53	5.26
Mid	0 (0.00X)	1975.63	218.17	39.45
Lower	29 (0.43X)	2228.0	229.02	4.87
Entire Field				16.53

¹N rate at economic optima as a fraction of entire-field recommended rate.

²Entire-field return calculated assuming equal proportions of the three units in the field.

Table W14: Analysis of variance for grain yield and protein for the P treatments.

Source	df	Grain yield	Grain protein
----- Mean squares -----			
Years (Y)	2	12430795**	138.628**
Landscape position (LP)	2	8637498*	0.275
Y*LP	4	769041***	0.483
Replications	5	256345	0.650
Treatment (T)	2	1463456	2.372
Y*T	4	229471*	6.693***
LP*T	4	132345	0.086
Y*LP*T	8	54825	0.255
Error	130	263118	0.330

*significance level: .05

**significance level: .01

***significance level: .001

Table W15: Effect of P fertilizer rate on grain yield across management units.

Landscape position	Grain yield (Kg ha ⁻¹)			
	0P1N	1P1N	2P1N	Across Treatments
----- 1997 -----				
Upper Slope	1641	2345	2248	2078
Midslope	1965	2341	2272	2193
Lower Slope	2716	2991	3079	2929
Column Mean	2108	2559	2533	2400
----- 1998 -----				
Upper Slope	661	927	1113	901
Midslope	1297	1857	1636	1597
Lower Slope	1900	1942	2071	1971
Column Mean	1286	1575	1607	1489
----- 1999 -----				
Upper Slope	1865	1935	2067	1956
Midslope	2127	2194	2386	2236
Lower Slope	2436	2317	2539	2431
Column Mean	2143	2149	2331	2207

Table W16: Effect of P fertilizer rate on grain protein across management units.

Landscape position	Grain protein (%)			
	0P1N	1P1N	2P1N	Across Treatments
<i>----- 1997 -----</i>				
Upper Slope	10.7	12.5	12.9	12.0
Midslope	11.3	12.6	12.5	12.2
Lower Slope	11.3	12.7	12.6	12.2
Column Mean	11.1	12.6	12.7	12.1
<i>----- 1998 -----</i>				
Upper Slope	14.6	14.1	14.1	14.3
Midslope	14.3	14.0	13.9	14.1
Lower Slope	14.4	14.1	13.8	14.1
Column Mean	14.4	14.1	13.9	14.1
<i>----- 1999 -----</i>				
Upper Slope	10.9	10.8	10.7	10.8
Midslope	11.1	10.8	10.9	10.9
Lower Slope	11.1	11.2	11.4	11.2
Column Mean	11.0	11.0	11.0	11.0

Table W17: Analysis of variance for grain yield and protein for the seeding rate treatments.

Source	df	Grain yield	Grain protein
----- Mean squares -----			
Years (Y)	2	14285754*	129.4596***
Landscape position (LP)	2	5747194	0.2428
Y*LP	4	990330***	0.6178*
Replications	5	260790	0.5591
Treatment (T)	2	1137153	0.1749
Y*T	4	173504	0.1331
LP*T	4	96836	0.0614
Y*LP*T	8	52592	0.1572
Error	129	242727	0.3129

*significance level: .05

**significance level: .01

***significance level: .001

Table W18: Effect of seeding rate on grain yield across management units.

Landscape position	Grain yield (Kg ha ⁻¹)			Across Treatments
	1.0 Bu ac ⁻¹	1.5 Bu ac ⁻¹	2.0 Bu ac ⁻¹	
----- 1997 -----				
Upper Slope	2222	2345	2248	2271
Midslope	2140	2341	2272	2251
Lower Slope	3034	2991	3079	3032
Column Mean	2429	2559	2533	2508
----- 1998 -----				
Upper Slope	894	927	1113	978
Midslope	1457	1857	1636	1650
Lower Slope	1534	1942	2071	1849
Column Mean	1295	1575	1607	1492
----- 1999 -----				
Upper Slope	1805	1935	2067	1936
Midslope	1874	2194	2386	2151
Lower Slope	1957	2317	2539	2271
Column Mean	1878	2149	2331	2119

Table W19: Effect of seeding rate on grain protein across management units.

Landscape position	Grain protein (%)			
	1.0 Bu ac ⁻¹	1.5 Bu ac ⁻¹	2.0 Bu ac ⁻¹	Across Treatments
----- 1997 -----				
Upper Slope	12.8	12.5	12.9	12.7
Midslope	12.8	12.6	12.5	12.7
Lower Slope	12.4	12.7	12.6	12.6
Column Mean	12.7	12.6	12.7	12.7
----- 1998 -----				
Upper Slope	14.3	14.1	14.1	14.2
Midslope	14.1	14.0	13.9	14.0
Lower Slope	14.3	14.1	13.8	14.1
Column Mean	14.2	14.1	13.9	14.1
----- 1999 -----				
Upper Slope	10.8	10.8	10.7	10.8
Midslope	11.0	10.8	10.9	10.9
Lower Slope	11.3	11.2	11.4	11.3
Column Mean	11.0	11.0	11.0	11.0

Table W20: Plant Available water over the growing season and across management units.

Landscape position	Plant available water (cm/0-30cm)				
	Spring	25 D.A.P.	50 D.A.P.	75 D.A.P.	Fall
1997					
Upper Slope	0.67	2.32	-0.26	-3.96 ⁰	-2.26
Midslope	1.45	3.59	0.77	-3.22	-0.15
Lower Slope	3.86	2.99	1.39	-2.26	0.29
Column Mean	2.00	2.97	0.64	-3.14	-0.71
1998					
Upper Slope	-0.18	-0.17	0.76	-0.82	-1.20
Midslope	1.33	1.35	2.58	0.09	-0.60
Lower Slope	1.63	1.87	3.13	0.21	-0.37
Column Mean	0.93	1.01	2.16	-0.17	-0.72
1999					
Upper Slope	1.08	1.31	-0.93	-2.12	-3.43
Midslope	2.52	2.40	0.41	-0.63	-2.33
Lower Slope	3.11	3.37	1.53	0.01	-1.76
Column Mean	2.23	2.36	0.34	-0.91	-2.50

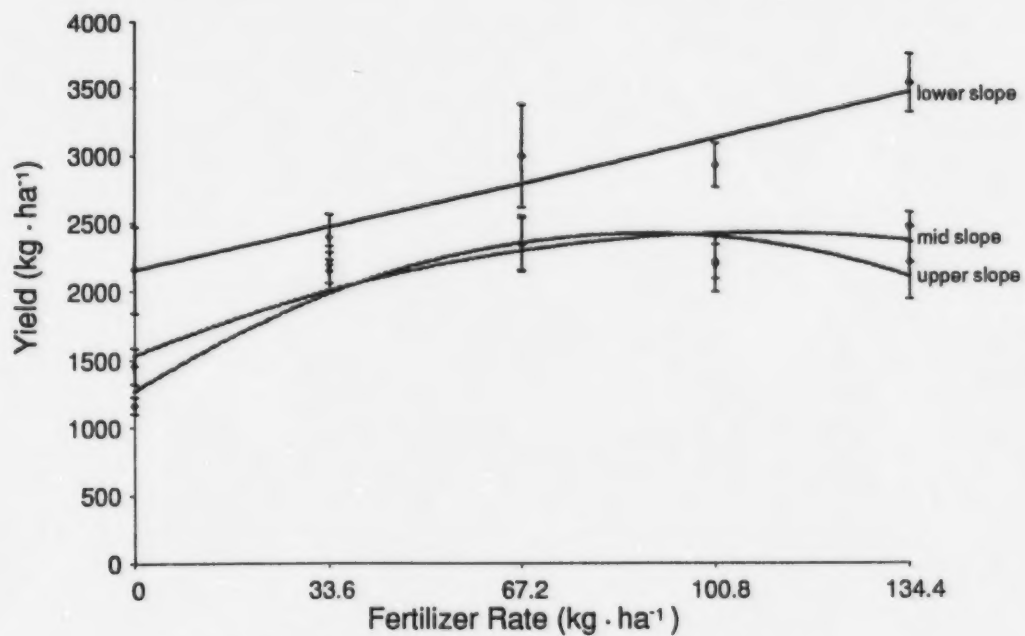


Figure W1: Fertilizer response curves, Watrous Wheat 1997

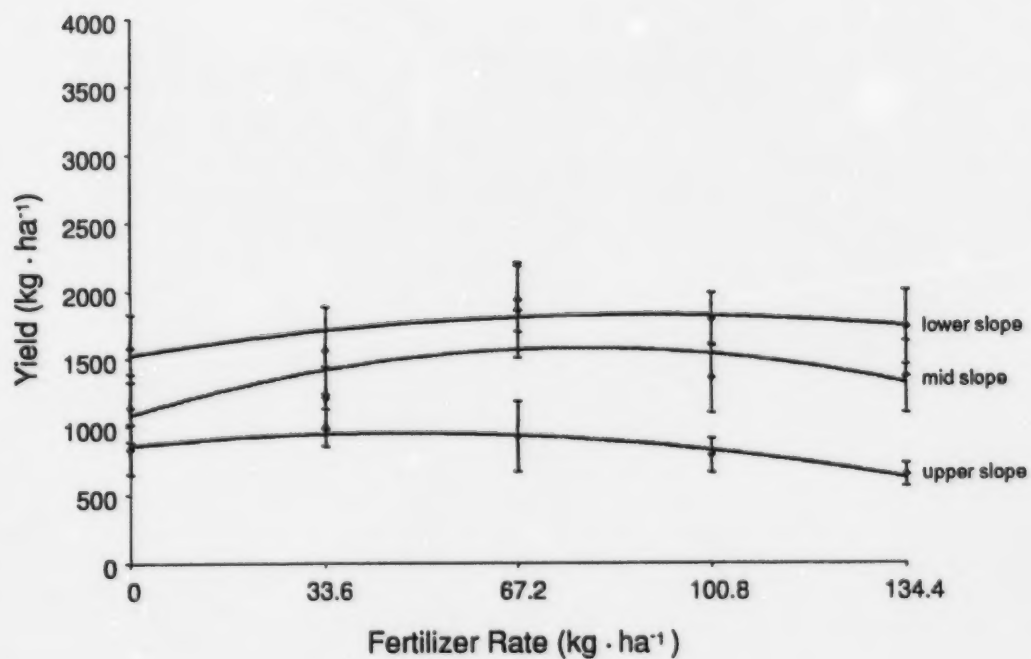


Figure W2: Fertilizer response curves, Watrous Wheat 1998

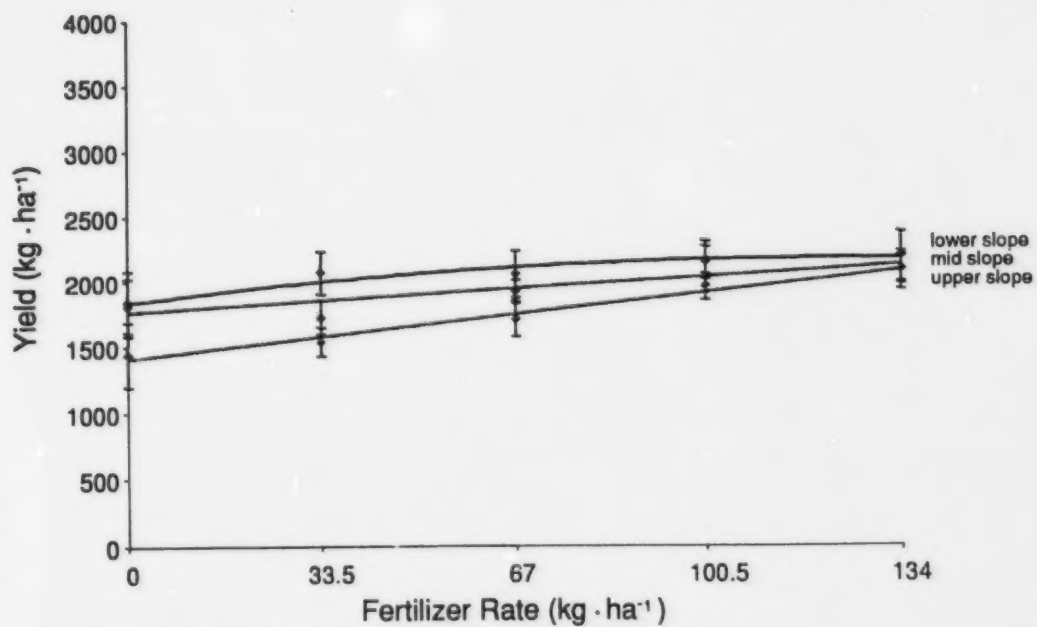


Figure W3: Fertilizer response curves, Watrous Wheat 1999

Outlook

The Outlook site was located on SE20-28-07-W3 on land owned by Mr. Pederson. The Outlook site was irrigated. The specific research site was located on a gently rolling section of a polygon mapped as the Elstow association. This association is in the Dark Brown soil zone and is formed on medium to medium-fine textured, moderately calcareous silty-glaciolacustrine deposits. Field operations at the Outlook site were carried out by Mr. Terry Hogg of the Canada-Saskatchewan Irrigation Diversification Corporation at Outlook.

Compared to the other sites, the variability in soil taxa and soil properties at the Outlook site is very limited, which is characteristic of landscapes with limited topography. The site is almost completely dominated by Orthic Chernozemic soils. Only five thin Orthic Regosolic soils were observed, and no Gleysolic soils were encountered in the study. The range in soil organic carbon values in the three management units was also very limited – the difference between upper and lower slope units is only 14 Mg ha^{-1} at this site, compared to a difference of 41.7 Mg ha^{-1} at Swift Current and 60.1 Mg ha^{-1} at Watrous.

At the Outlook site the major factor controlling management unit variations, soil moisture, was managed directly through irrigation. Total water applied varied from 453.2 mm in 1997 to 286.3 mm in 1999 (Table O3). No sharp frosts were experienced after emergence of the crop in any year of the study.

The spring available water values at Outlook had much less relevance than at the other sites, but nonetheless a strong landscape pattern was observed in all three years of the study. In all three years no significant difference was observed between upper and

mid slope units, but both of these were significantly drier than the lower slope units. The driest conditions at the time of seeding occurred in 1998 when the upper and mid slope units were below permanent wilting point at the time of seeding.

The spring available N levels showed considerable year-to-year variations but no management unit effect across the three years of the study (Table O5). This lack of landscape variation in N levels was unsurprising given the lack of soil differences between the management units as discussed above.

Nitrogen Treatments

The overall ANOVA for the effect of the N treatments on grain yield and protein at the Outlook site indicates several main points (Table O6). First, there were strong year-to-year variations in grain yields and protein at this site, and this caused significant interactions between management unit and treatment to occur. Second, there was no overall difference between the management units at this site in terms of yield or protein, although there were differences between the years. Finally treatment, and its interactions with year, was significant for both yield and protein.

The large year effect was caused by the low crop yields (for this site) in 1998 (Table O7). The spring soil moisture conditions in 1998 were the driest in any year of the study and only 16.7 mm of irrigation water was added in the first 25 DAP (compared to 48.2 mm from 26 to 50 DAP and 109.4 mm from 51 to 75 DAP). We believe that this relatively dry condition in the first 25 DAP led to reduced crop yields in this year. The limited competition from the establishing wheat crop early in the growing season also led

to significant weed pressure in this year. The protein levels overall were inversely related to yields in the three years of the study.

There were only small differences in yield and protein across the three management units over the three years of the study (Table O8). The trend for yield was similar to the other sites (i.e., upper<mid<lower) but the differences are not significant either statistically or agronomically. Again the limited soil differences and the use of irrigation to remove soil moisture differences clearly limits the differences between the management units at this site.

The only year that showed a pronounced management unit effect was 1998, which was a relatively dry year. The differences in grain yield between upper and lower slopes was 770 kg ha^{-1} in this year compared to 422 kg ha^{-1} in 1997 and only 140 kg ha^{-1} in 1999. The range in protein contents between the management units was also highest in 1998.

The yield functions for wheat (Figure O1 to O3) and associated yields (Table O11) are very similar in form but with absolute differences that reflect the year-to-year variations. In 1997 and 1998 there was an inherent productivity difference between the management units at the 0XN rate. In 1997 this difference was lost at the recommended rate (1X) and the response curves converged at the 2XN rate. In 1998 the curves are very similar in form but the small differences between the rates are consistent throughout the full range of treatments. In 1999 there was no difference, whatsoever, between the curves in either their intercepts or forms.

The economic calculations for Outlook for all three years are striking in two ways (Table O13). First, the economic N rates differed very little between the three

management units in a given year. Second, the return of the optimum VRF rate compared to the 1X rate was very small in all three years of the study – for example, the return associated with the optimum VRF rate is only \$0.04 ha⁻¹ higher than the 1X rate in 1998.

The results for the Outlook site clearly show that there was no agronomic or economic rationale for the implementation of topographically based VRF N fertilization at this site. As well, the data clearly indicated that the current soil test recommendations for N inputs under irrigation are accurate.

Phosphorus and Seeding Rate Treatments

Neither the phosphorus (Table O14) or seeding rate treatments (Table O17) showed a consistent treatment effect at Outlook. As with the N treatments there was no consistent management unit effect for either treatment. The yields, for both treatments, showed the same annual variation that the N treatments yield did.

The response to P fertilizer rates in each year of the study was limited (Table O15). In 1997, no yield response to P occurred (averaged across management units). In 1998 and 1999, a yield increase of approximately 400 kg ha⁻¹ occurred from the OP rate to the 1XP rate but only small changes occurred between the 1XP and 2XP rates. The same lack of response was seen for grain protein (Table O16).

The same lack of response is true for the seeding rate treatments at this site (Table O18, O19). It seems unlikely that seeding rate will form part of a VR program in these irrigated landscapes.

Table O1: Distribution of soil subgroups in the management units. The subgroups are arrayed in approximate order from driest to wettest. These results are tabulated from the three years of the study.

Orders and Soil Subgroup	Upper Slope	Midslope	Lower Slope
<i>Regosolic</i>			
Orthic	5		
<i>Chernozemic Dark Brown</i>			
Rego	5		5
Calcareous		2	
Orthic	56	64	58
Eluviated			3

Table O2: Mean soil organic carbon in the management units. These results are tabulated from the three years of the study.

Management Unit	Soil organic carbon. (Mg ha ⁻¹)
Upper	75.3 ^a
Mid	77.0 ^a
Lower	89.2 ^b
<i>Grand mean</i>	80.5

Table O3: Growing season climate statistics; precipitation, growing degree days, and significant events.

Site	Seeding Date	Seeding to 25DAP	26DAP to 50DAP	51DAP to 75DAP	76DAP to Harvest	Growing Season Precipitation	Growing Degree Days (base 5°C)
----- Precipitation (mm) -----							
1997	May 5	21.8	67.0	157.8	23.6	270.2 (453.2) ¹	1412
1998	May 13	31.0	70.9	15.3	24.2	141.4 (348.5)	1506
1999	May 19	36.7	97.1	44.3	16.8	194.9 (286.3)	1212
30 year average ²						179.9	1381
Significant Events							
Date	Frost (Minimum Temperature C)		Precipitation Greater than 20mm				
1997	May 8	-1.5	July 5	21.9			
	May 14	-0.4	July 6	22.7			
			July 17	22.7			
1998	May 13	-6.0	June 19	37.2			
	June 3	-0.9					
1999			June 24	30.5			

¹Total Precipitation-Seeding to Harvest, vales in parenthesis represent sum of precipitation and irrigation water applied.

²30 year averages, May 1 – September 31, obtained from the nearest Environment Canada Meteorological Station.

Table O4: Plant available water; pre-seeding.

Landscape Position	1997	1998	1999	Across years
----- cm available water per 90 cm soil -----				
Upper	0.05 ^a	-1.71 ^a	0.66 ^a	-0.26 ^a
Mid	1.24 ^a	-2.49 ^a	1.68 ^a	0.34 ^a
Lower	4.52 ^b	3.88 ^b	7.37 ^b	5.12 ^b
Grand mean	1.94	-0.11	3.23	1.73

Table O5: Soil nitrate; pre-seeding.

Landscape Position	1997	1998	1999	Across years
	----- Kg ha ⁻¹ to 60 cm -----			
Upper	63.8	32.3	74.4	54.5 ^a
Mid	60.6	35.8	79.4	54.4 ^a
Lower	57.8	56.2	86.0	60.4 ^a
Grand mean	60.7	41.4	79.9	56.4

Table O6: Analysis of variance for grain yield and protein for the N treatments.

Source	df	Grain yield	Grain protein
		----- Mean squares -----	
Years (Y)	2	143873659***	59.4807**
Landscape position (LP)	2	2812282	8.0429
Y*LP	4	1640415***	3.8024***
Replications	5	159576	0.9408**
Treatment (T)	4	10542378***	28.0125**
Y*T	8	620983***	2.7394***
LP*T	8	85590	0.6249*
Y*LP*T	16	104231	0.1885
Error	220	74480	53.8305

*significance level: .05

**significance level: .01

***significance level: .001

Table O7: Mean grain yield and protein averaged across treatments and landscape position.

Year	Grain yield (kg ha ⁻¹)	Grain protein (%)
1997	4193 ^a	13.6 ^a
1998	2085 ^b	14.7 ^b
1999	4349 ^a	13.2 ^c
Grand mean	3542	13.8

Table O8: Mean grain yield and protein averaged across years and treatments.

Year	Grain yield	Grain protein
	(kg ha ⁻¹)	(%)
Upper	3381 ^a	13.6 ^a
Mid	3514 ^{ab}	13.7 ^a
Lower	3731 ^b	14.2 ^b
<i>Grand mean</i>	3542	13.8

Outlook 9: Mean spring grain yield averaged across N treatments.

Landscape Position	1997	1998	1999
	Kg ha ⁻¹		
Upper	3995 ^a	1742 ^a	4406 ^a
Mid	4167 ^{ab}	2002 ^a	4374 ^a
Lower	4417 ^b	2511 ^b	4266 ^a
<i>Grand mean</i>	4193	2085	4349

Table O10: Mean spring grain protein averaged across N treatments.

Landscape Position	1997	1998	1999
	%		
Upper	13.2 ^a	14.3 ^a	13.3 ^a
Mid	13.4 ^a	14.6 ^a	13.2 ^a
Lower	14.2 ^b	15.3 ^b	13.1 ^a
<i>Grand mean</i>	13.6	14.7	13.2

Table O11: Effect of N fertilizer rate on grain yield across management units.

Landscape position	Grain Yield (Kg ha ⁻¹)				
	0N1P	0.5N1P	1N1P	1.5N1P	2N1P
-----1997-----					
Upper Slope	3111	3617	4006	4632	4611
Midslope	3384	3941	4313	4703	4492
Lower Slope	3964	4309	4362	4793	4657
Column Mean	3487	3956	4227	4709	4587
-----1998-----					
Upper Slope	915	1672	1992	1963	2170
Midslope	1111	1938	2298	2340	2324
Lower Slope	1597	2341	2805	3062	2750
Column mean	1208	1984	2365	2455	2415
-----1999-----					
Upper Slope	3847	4280	4882	4667	4354
Midslope	3819	4377	4751	4632	4291
Lower Slope	3744	4155	4567	4613	4253
Column Mean	3803	4271	4734	4637	4299

Table O12: Effect of N fertilizer rate on grain protein across management units.

Landscape position	Grain Protein (%)				
	0N1P	0.5N1P	1N1P	1.5N1P	2N1P
-----1997-----					
Upper Slope	12.1	12.0	12.8	14.1	15.0
Midslope	12.3	12.3	13.3	14.3	14.9
Lower Slope	13.4	13.6	14.1	14.7	15.1
Column Mean	12.6	12.6	13.4	14.4	15.0
-----1998-----					
Upper Slope	13.6	14.2	14.2	14.8	14.9
Midslope	13.9	14.9	14.4	15.0	14.9
Lower Slope	14.8	15.1	15.5	15.7	15.5
Column mean	14.1	14.7	14.7	15.2	15.1
-----1999-----					
Upper Slope	12.3	12.7	13.3	13.9	14.2
Midslope	12.3	12.4	13.5	13.8	14.1
Lower Slope	12.4	12.5	13.2	13.5	13.6
Column Mean	12.3	12.5	13.3	13.7	14.0

Table O13: Economic Optima Nitrogen Rates and Net Returns. Calculations assume $N@\$0.587 \text{ kg}^{-1}$ and $wheat@\$0.11043 \text{ kg}^{-1}$ for a price ratio of 5.3156.

Unit	N Rate at Economic Optima ----- Kg ha^{-1} -----	Yield at Economic Optima ----- Kg ha^{-1} -----	Net Return at Economic Optima ----- $\$ \text{ha}^{-1}$ -----	Minus Net Return at 1X Rate
----- 1997 -----				
Upper	159 (1.42X) ¹	4515.76	405.34	5.04
Mid	109 (0.97X)	4454.6	427.93	0.04
Lower	74 (0.66X)	4004.3	398.76	4.93
Entire Field ²				3.34
----- 1998 -----				
Upper	107 (0.96X)	1922.8	149.53	0.09
Mid	109 (0.97X)	2272.9	187.01	0.04
Lower	113 (1.01X)	2847.0	248.07	0.00
Entire Field				0.04
----- 1999 -----				
Upper	85 (0.76X)	4629.7	461.37	4.17
Mid	82 (0.73X)	4590.3	458.77	5.33
Lower	81 (0.72X)	4415.5	440.06	4.57
Entire Field				4.69

¹N rate at economic optima as a fraction of entire-field recommended rate.

²Entire-field return calculated assuming equal proportions of the three units in the field.

Table O14: Analysis of variance for grain yield and protein for the P treatments.

Source	df	Grain yield	Grain protein
		----- Mean squares -----	
Years (Y)	2	84854389***	27.0511*
Landscape position (LP)	2	600980	7.6751
Y*LP	4	1053621***	3.3823***
Replications	5	138803	0.5507**
Treatment (T)	2	1574499	0.7560
Y*T	4	781554***	0.4805**
LP*T	4	100048	0.2067*
Y*LP*T	8	41576	0.0534
Error	130	79504	0.1433

*significance level: .05

**significance level: .01

***significance level: .001

Table O15: Effect of P fertilizer rate on grain yield across management units.

Landscape position	Grain yield (Kg ha ⁻¹)			
	0P1N	1P1N	2P1N	Across Treatments
----- 1997 -----				
Upper Slope	4349	4006	4308	4221
Midslope	4479	4313	4435	4409
Lower Slope	4350	4362	4639	4450
Column Mean	4393	4227	4461	4360
----- 1998 -----				
Upper Slope	1666	1992	2137	1932
Midslope	1955	2298	2495	2249
Lower Slope	2117	2805	2905	2609
Column Mean	1913	2365	2512	2263
----- 1999 -----				
Upper Slope	4291	4882	4716	4630
Midslope	4350	4751	4487	4529
Lower Slope	4071	4567	4400	4346
Column Mean	4238	4734	4534	4502

Table O16: Effect of P fertilizer rate on grain protein across management units.

Landscape position	Grain protein (%)			
	0P1N	1P1N	2P1N	Across Treatments
<i>----- 1997 -----</i>				
Upper Slope	12.9	12.8	12.8	12.9
Midslope	13.5	13.3	13.3	13.4
Lower Slope	13.9	14.1	14.1	14.0
Column Mean	13.4	13.4	13.4	13.4
<i>----- 1998 -----</i>				
Upper Slope	13.9	14.2	14.2	14.1
Midslope	14.1	14.4	14.5	14.3
Lower Slope	14.8	15.5	15.7	15.3
Column Mean	14.2	14.7	14.8	14.6
<i>----- 1999 -----</i>				
Upper Slope	13.4	13.3	13.5	13.4
Midslope	13.2	13.5	13.3	13.3
Lower Slope	13.1	13.2	13.3	13.2
Column Mean	13.2	13.3	13.3	13.3

Table O17: Analysis of variance for grain yield and protein for the seeding rate treatments.

Source	df	Grain yield	Grain protein
----- Mean squares -----			
Years (Y)	2	84487474***	37.1650*
Landscape position (LP)	2	1172948	9.6385
Y*LP	4	1499448***	2.9200***
Replications	5	119624	0.7131**
Treatment (T)	2	936516	0.1010
Y*T	4	569814***	0.0832
LP*T	4	13312	0.0565
Y*LP*T	8	30557	0.0913
Error	130	82565	0.2220

*significance level: .05

**significance level: .01

***significance level: .001

Table O18: Effect of seeding rate on grain yield across management units.

Landscape position	Grain yield (Kg ha ⁻¹)			Across Treatments
	1.0 Bu ac ⁻¹	1.5 Bu ac ⁻¹	2.0 Bu ac ⁻¹	
----- 1997 -----				
Upper Slope	4204	4006	4308	4173
Midslope	4281	4313	4435	4343
Lower Slope	4630	4362	4639	4544
Column Mean	4372	4227	4461	4353
----- 1998 -----				
Upper Slope	1545	1992	2137	1891
Midslope	1999	2297	2495	2264
Lower Slope	2449	2805	2905	2720
Column Mean	1998	2365	2512	2292
----- 1999 -----				
Upper Slope	4493	4882	4716	4697
Midslope	4473	4751	4487	4570
Lower Slope	4177	4567	4400	4381
Column Mean	4381	4734	4534	4550

Table O19: Effect of seeding rate on grain protein across management units.

Landscape position	Grain protein (%)			
	1.0 Bu ac ⁻¹	1.5 Bu ac ⁻¹	2.0 Bu ac ⁻¹	Across Treatments
<i>----- 1997 -----</i>				
Upper Slope	12.6	12.8	12.8	12.8
Midslope	13.1	13.3	13.3	13.3
Lower Slope	13.9	14.1	14.1	14.1
Column Mean	13.2	13.4	13.4	13.4
<i>----- 1998 -----</i>				
Upper Slope	14.3	14.2	14.2	14.2
Midslope	14.8	14.4	14.5	14.6
Lower Slope	15.3	15.5	15.7	15.5
Column Mean	14.8	14.7	14.8	14.8
<i>----- 1999 -----</i>				
Upper Slope	13.2	13.3	13.5	13.3
Midslope	13.3	13.5	13.3	13.4
Lower Slope	13.3	13.2	13.3	13.3
Column Mean	13.3	13.3	13.3	13.3

Table O20: Plant Available water over the growing season and across management units.

Landscape position	Plant available water (cm/0-30cm)				
	Spring	25 D.A.P.	50 D.A.P.	75 D.A.P.	Fall
<i>----- 1997 -----</i>					
Upper Slope	1.99	2.64	-0.63	0.69	0.54
Midslope	1.88	2.48	-1.08	0.85	0.01
Lower Slope	2.80	3.51	-0.22	1.16	0.31
Column Mean	2.22	2.88	-0.64	0.90	0.29
<i>----- 1998 -----</i>					
Upper Slope	1.27	1.74	2.54	0.79	0.69
Midslope	0.12	-0.34	1.31	-0.98	-0.91
Lower Slope	2.27	1.84	2.69	0.82	1.38
Column Mean	1.22	1.08	2.18	0.21	0.39
<i>----- 1999 -----</i>					
Upper Slope	2.31	2.13	3.23	0.03	-2.07
Midslope	1.85	2.06	3.00	-0.39	-2.17
Lower Slope	3.40	3.51	4.59	1.36	-0.61
Column Mean	2.52	2.56	3.61	0.33	-1.62

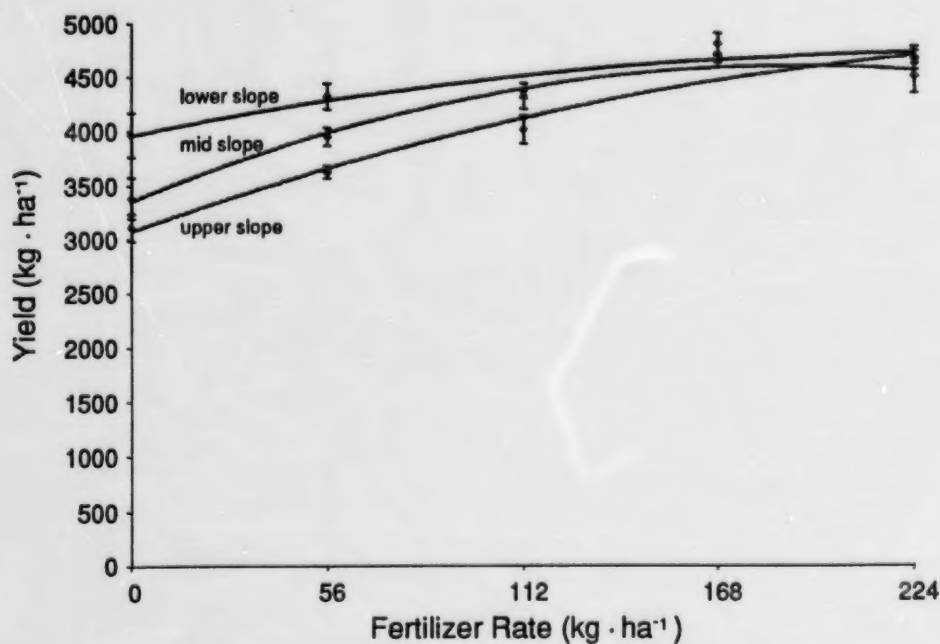


Figure O1: Fertilizer response curves, Outlook Wheat 1997

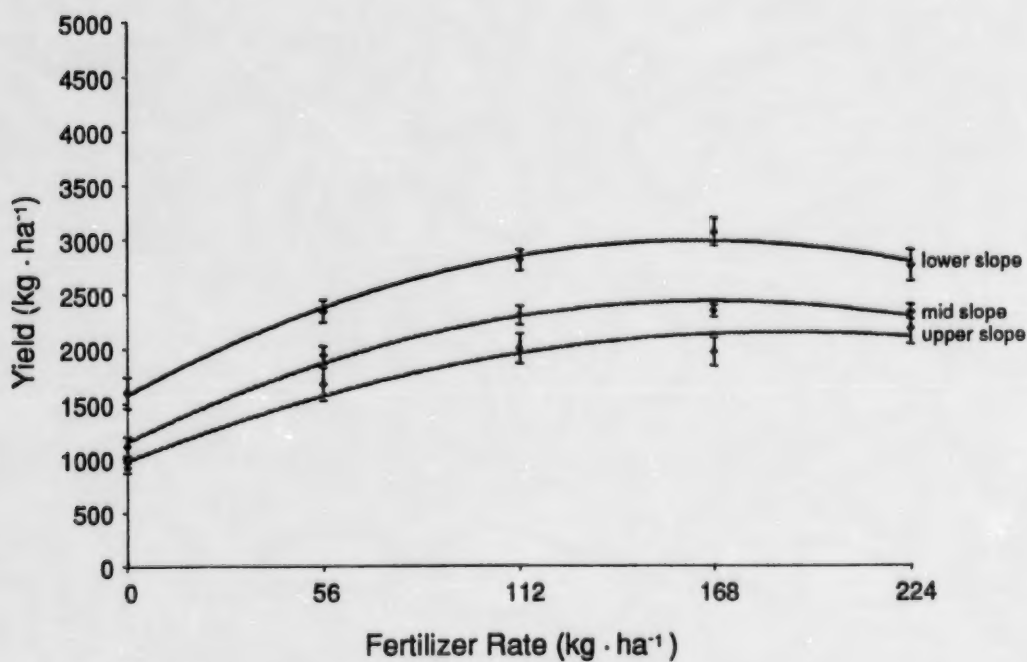


Figure O2: Fertilizer response curves, Outlook Wheat 1998

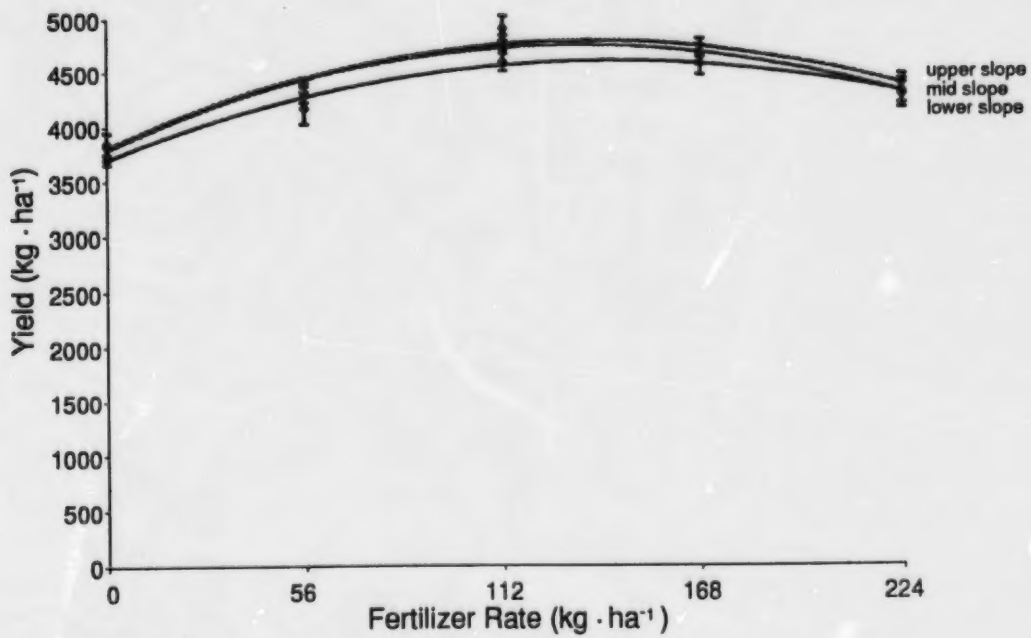


Figure O3: Fertilizer response curves, Outlook Wheat 1999

Conservation Learning Center Site (St. Louis, Saskatchewan)

The Conservation Learning Center (CLC) site was located at SE20-46-26-W2. The site is mapped as a Hamlin-Blaine Lake 5 map unit on a slope class 4-3 hummocky surface. The Hamlin association soils form in very fine sandy loam glaciolacustrine sediments and the Blaine Lake soils are dominantly silty glaciolacustrine. The surface soils are formed on a very thick deposit of glaciolacustrine sediments that were originally formed on top of the ice sheet (i.e. supraglacial lacustrine). As the ice sheet melted the lacustrine sediments deformed and flowed, resulting in the characteristic hummocky surface form. The entire surface is formed of highly curved slope elements, and no midslope units could be mapped at this site. Hence, unlike the other sites, only two management units were used at this site. All field operations at this site were carried out by Dr. Adrian Johnston, previously of the AAFC Melfort Research Station and now at the Potash and Phosphate Institute of Canada. The CLC is managed by Ms. L. Hayes.

The CLC site is located on thick black soils within the Black soil zone. Soils in this region generally have high amounts of SOC storage throughout the profile. The thick nature of the soil is reflected in the distribution of soils at this site (Table C1). The great majority of the soils are Orthic Black Chernozemic soils. A few Rego and Calcareous soils were found, but no Orthic Regosolic soils were observed. Hence the upper slope units at this site do not have the highly eroded, high lime soils characteristic of the glacial till sites. The lower slope soils are dominated by Orthic Chernozemic soils and only a few Gleysolic soils were observed. At the CLC, many of the larger sloughs (i.e., those normally occupied by Gleysolic soils) are permanently water-filled and are not cropped.

The organic-rich nature of the soils at the CLC is reflected in the high SOC values for both landscape positions (Table C2). The upper slope units had an average SOC level of 93.9 Mg ha⁻¹, which is 20 Mg ha⁻¹ higher than the comparable units at the Watrous site. The range between upper and lower slope units at this site is only 27.5 Mg ha⁻¹, which is considerably lower than either of the glacial till sites. Hence although there is a range of soils at the CLC, the SOC levels are high to very high in all management units.

With the exception of 1998, growing season precipitation was well distributed throughout the growing season (Table C3). In 1998 the first 25 days after seeding were quite dry and the next period had several heavy rainfalls. The 113-mm rainfall on July 5 caused some flooding in the lower slope units, which effected crop growth. In 1999, several moderate rainfalls occurred, which kept soil moisture conditions high throughout the growing season but without significant flooding. The potential for flooding of lower slope positions in these landscapes is high due to the much higher precipitation levels, and hence scenarios for higher fertility inputs in these positions would be inherently risky.

Soil moisture conditions at the time of seeding were high to very high in all three years of the study (Table C4). Although a management unit effect across years was observed, the soil moisture conditions across the entire landscape were very good compared to the other sites we examined. Hence the major differences in soil moisture conditions were not observed at this site.

Spring available N levels in 1997 and 1998 did not show a difference between the management units (Table C5). In 1999 the N levels were high in both positions, which

reflects the later seeding date (and higher N mineralization prior to seeding). The N levels were significantly higher in the lower slope positions in that year.

Nitrogen Treatments

The overall ANOVA for the N treatments at the CLC site differed considerably from those of the other research sites (Table C6). For grain yield, only the N treatments themselves showed a significant result; neither year-to-year nor management unit effects were of significance. For protein, the annual differences were of importance, and treatment again was a significant effect.

The lack of a significant year effect can be seen in the yields for the three years (Table C7). The yields increased from 1997 through to 1999, but the overall difference between the years was small relative to some of the other sites. Protein contents were again inversely related to yields and the highest protein levels occurred in 1997 and the lowest in 1999. The major difference in protein occurs between the high 15.5% protein in 1997 versus the lower protein levels achieved in the other two years of the study.

The difference between the two management units for yield and protein across the three years of the study are very small (Table C8). For yield, the difference of both the upper and lower units from the grand mean was less than 200 kg ha^{-1} . Similarly, for protein the difference was less than 0.2%.

For yields within years, the difference between management units was most pronounced in 1997 (Table C9). Interestingly, 1997 was also the driest year at this location, both in terms of spring moisture and growing season precipitation. The difference between management units was lost in the wetter years of 1998 and 1999. This

finding reinforces the point that the differences between the management units were primarily driven by soil moisture. If the differences in soil moisture are not present, then the management unit effect is not of importance. No major differences were noted for differences in grain protein between the management units.

The N treatments showed a strong effect of both grain yield and protein (Figure C 1-3, Tables C11, C12). For the three years of the study there was a major increase in yield from the 0XN to the 0.5XN rate. This increase was more pronounced in the upper slope than in the lower slope unit. Consistently in the three years of the study, yields declined slightly from the 1XN rate to the 1.5XN rate but then increased to the 2XN rate. The reasons for this slight yield decrease at the 1.5XN rate are not known to us.

The protein response to the added N fertilizer was most pronounced in 1997 (the driest year at this site). The maximum protein contents achieved (17.6%) are very high for this region. The differences in protein contents among the treatments was lowest in the wettest year, 1999.

From an economic perspective, the optimum rates in 1997 were well below the 1X recommended rate. In the drier conditions (for this site) experienced in that year the crop was unable to take advantage of the higher N rates. In 1998 and 1999 the optimum location for placing the higher rates was inverted - in 1998 the higher rates of fertilizer N yielded maximum returns in the lower slope units and in 1999 the higher fertilizer N rates yielded maximum returns in the upper slope units. The higher rates required on the upper slope units in 1999 was the only example in all the site years of this study where there was a significant economic benefit to higher N rates on the upper slopes than the lower slope units. The overall net return from optimum (i.e., with perfect hindsight) VRF

fertilization compared to the standard 1XN rate is about \$11.50 ha⁻¹ over the three years of the study.

Phosphorus and Seeding Rate Treatments

Neither the P treatments or the seeding rate treatments showed much promise for variable rate treatments at this site (Table C14 to C17). The overall ANOVA table for the P treatments indicates that no significant effects occurred for any of the treatments or factors at this site. The lack of a P treatment effect is striking insofar as this means there was no significant effect for the added P fertilizer at this site. An increase overall between the 0P and 1P treatment was seen in 1999, but otherwise the response to P was very limited. The same is true for the seeding rate treatments – the effect of the seeding rate was very small across management units and across years of the study.

TABLE C1: Distribution of soil subgroups in the management units. The subgroups are arrayed in approximate order from driest to wettest. These results are tabulated from the three years of the study.

Orders and Soil Subgroup	Upper Slope	Lower Slope
<i>Chernozemic Black</i>		
Rego	3	2
Calcareous	2	1
Orthic	61	47
Eluviated		3
Gleyed		9
<i>Gleysolic</i>		
Orthic Humic		4

TABLE C2: Mean soil organic carbon in the management units. These results are tabulated from the three years of the study.

Management Unit	Soil organic carbon. (Mg ha ⁻¹)
Upper	93.9 ^a
Lower	121.4 ^b
<i>Grand mean</i>	107.7

TABLE C3: Growing season climate statistics; precipitation, growing degree days, and significant events.

Site	Seeding Date	Seeding to 25DAP	26DAP to 50DAP	51DAP to 75DAP	76DAP to Harvest	Growing Season Precipitation	Growing Degree Days (base 5°C)
----- Precipitation (mm) -----							
1997	May 31	65.0	80.4	15.1	26.3	186.8 ¹	1335
1998	May 19	7.4	196.5	48.8	32.4	285.1	1401
1999	May 31	80.3	172.7	40.6	47.8	341.4	1194
30 year average ²						225.9	1165
Significant Events							
Date	Frost (Minimum Temperature C)			Precipitation Greater than 20mm			
1997	May 14	-5.1		June 8	27.9		
	May 15	-0.9		June 20	20.3		
	May 17	-1.2		June 21	41.9		
1998	May 31	-2.4		June 19	39.9		
	June 2	-0.1		July 5	113.3		
	June 3	-1.7		July 20	21.5		
	June 6	-0.3					
1999	September 2	-0.5		June 25	30.5		
	September 14	-4.1		June 26	27.9		
				July 6	68.5		
				July 15	50.8		
				July 23	25.4		
				August 16	27.9		

¹Total Precipitation-Seeding to Harvest.

²30 year averages, May 1 – September 31, obtained from the nearest Environment Canada Meteorological Station.

TABLE C4: Plant available water; pre-seeding.

Landscape Position	1997	1998	1999	Across years
	----- <i>cm available water per 90 cm soil</i> -----			
Upper	5.37 ^a	5.68 ^a	7.55 ^a	6.05 ^a
Lower	9.90 ^b	13.73 ^b	13.02 ^b	11.80 ^b
<i>Grand mean</i>	7.64	9.70	10.29	8.92

TABLE C5: Soil nitrate; pre-seeding.

Landscape Position	1997	1998	1999	Across years
	----- <i>Kg ha⁻¹ to 60 cm</i> -----			
Upper	64.2 ^a	58.7 ^a	72.1 ^a	
Lower	58.0 ^a	40.8 ^a	95.2 ^b	
<i>Grand mean</i>	61.1	49.8	83.6	

TABLE C6: Analysis of variance for grain yield and protein for the N treatments.

Source	df	Grain yield	Grain protein
		----- <i>Mean squares</i> -----	
Years (Y)	2	8656471	142.370***
Landscape position (LP)	1	6187684	4.456
Y*LP	2	776258	2.267
Replications	5	245286	1.703*
Treatment (T)	4	2440640**	28.542*
Y*T	8	264504	7.099
LP*T	4	176646	0.563
Y*LP*T	8	415743	0.663
Error	145	444247	0.712

*significance level: .05

**significance level: .01

***significance level: .001

TABLE C7: Mean grain yield and protein averaged across treatments and landscape position.

Year	Grain yield (kg ha ⁻¹)	Grain protein (%)
1997	2199 ^a	15.5 ^a
1998	2579 ^b	13.1 ^b
1999	2959 ^c	12.7 ^b
<i>Grand mean</i>	2579	13.8

TABLE C8: Mean grain yield and protein averaged across years and treatments.

Year	Grain yield	Grain protein
	(kg ha ⁻¹)	(%)
Upper	2394 ^a	13.6 ^a
Lower	2764 ^b	13.9 ^a
<i>Grand mean</i>	2579	13.8

TABLE C9: Mean spring grain yield averaged across N treatments.

Landscape Position	1997	1998	1999
	Kg ha ⁻¹		
Upper	1886 ^a	2431 ^a	2864 ^a
Lower	2512 ^b	2727 ^a	3054 ^a
<i>Grand mean</i>	2199	2579	2959

TABLE C10: Mean spring grain protein averaged across N treatments.

Landscape Position	1997	1998	1999
	%		
Upper	15.6 ^a	13.0 ^a	12.3 ^a
Lower	15.5 ^a	13.2 ^a	13.1 ^b
<i>Grand mean</i>	15.5	13.1	12.7

TABLE C11: Effect of N fertilizer rate on grain yield across management units.

Landscape position	Grain Yield (Kg ha ⁻¹)				
	0N1P	0.5N1P	1N1P	1.5N1P	2N1P
-----1997-----					
Upper Slope	1699	1915	2100	1965	1752
Lower Slope	2140	2538	2610	2605	2669
Column Mean	1920	2227	2355	2285	2211
-----1998-----					
Upper Slope	1915	2420	2442	2579	2797
Lower Slope	2400	2552	2842	2564	3275
Column mean	2157	2486	2642	2571	3036
-----1999-----					
Upper Slope	1903	2828	3116	2997	3477
Lower Slope	2829	3109	3104	3208	3021
Column Mean	2366	2969	3110	3103	3249

TABLE C12: Effect of N fertilizer rate on grain protein across management units.

Landscape position	Grain Protein (%)				
	0N1P	0.5N1P	1N1P	1.5N1P	2N1P
1997					
Upper Slope	12.9	14.8	16.1	16.5	17.6
Lower Slope	13.4	14.4	15.4	17.1	17.3
Column Mean	13.1	14.6	15.8	16.8	17.4
1998					
Upper Slope	11.9	13.0	12.7	13.5	13.7
Lower Slope	12.1	13.1	13.4	13.7	13.7
Column mean	12.0	13.1	13.0	13.6	13.7
1999					
Upper Slope	12.2	12.0	11.7	12.6	13.2
Lower Slope	12.9	12.6	13.2	13.2	13.4
Column Mean	12.6	12.3	12.5	12.9	13.3

TABLE C13: Economic Optima Nitrogen Rates and Net Returns. Calculations assume $N@\$0.587 \text{ kg}^{-1}$ and $wheat@\$0.11043 \text{ kg}^{-1}$ for a price ratio of 5.3156.

Unit	N Rate at Economic Optima ----- Kg ha^{-1} -----	Yield at Economic Optima -----	Net Return at Economic Optima ----- $\$ \text{ha}^{-1}$ -----	Minus Net Return at 1X Rate
-----1997-----				
Upper	33 (0.41X) ¹	1920.0	192.65	12.73
Lower	42 (0.53X)	2464.2	247.47	5.20
Entire Field ²				8.97
-----1998-----				
Upper	74 (1.32)	2606.1	244.35	1.58
Lower	160 (2.86)	3473.0	289.60	17.83
Entire Field				9.71
-----1999-----				
Upper	88 (1.47X)	3568.8	342.45	26.01
Lower	32 (0.53X)	3075.6	320.86	5.78
Entire Field				15.90

¹N rate at economic optima as a fraction of entire-field recommended rate.

²Entire-field return calculated assuming equal proportions of both management units.

TABLE C14: Analysis of variance for grain yield and protein for the P treatments.

Source	df	Grain yield	Grain protein
----- Mean squares -----			
Years (Y)	2	3304578	119.531
Landscape position (LP)	1	5093405	1.114
Y*LP	2	416221	7.423*
Replications	5	228068	1.769**
Treatment (T)	2	467149	0.338
Y*T	4	189014	0.375
LP*T	2	134938	0.849
Y*LP*T	4	111291	0.528
Error	85	322014	0.548

*significance level: .05

**significance level: .01

***significance level: .001

TABLE C15: Effect of P fertilizer rate on grain yield across management units.

Landscape position	Grain yield (Kg ha ⁻¹)			
	0P1N	1P1N	2P1N	Across Treatments
----- 1997 -----				
Upper Slope	2008	2100	2097	2069
Lower Slope	2567	2610	2655	2611
Column Mean	2288	2355	2376	2340
----- 1998 -----				
Upper Slope	2115	2442	2395	2317
Lower Slope	3004	2842	2828	2892
Column Mean	2560	2642	2612	2604
----- 1999 -----				
Upper Slope	2563	3116	2873	2851
Lower Slope	2730	3104	3278	3037
Column Mean	2647	3110	3076	2944

TABLE C16: Effect of P fertilizer rate on grain protein across management units.

Landscape position	Grain protein (%)			
	0P1N	1P1N	2P1N	Across Treatments
<i>----- 1997 -----</i>				
Upper Slope	15.9	16.1	16.3	16.1
Lower Slope	15.7	15.4	15.5	15.5
Column Mean	15.8	15.8	15.9	15.8
<i>----- 1998 -----</i>				
Upper Slope	12.9	12.7	13.3	12.9
Lower Slope	12.3	13.4	13.0	12.9
Column Mean	12.6	13.0	13.1	12.9
<i>----- 1999 -----</i>				
Upper Slope	11.9	11.7	11.9	11.8
Lower Slope	13.1	13.2	12.8	13.0
Column Mean	12.5	12.5	12.4	12.4

TABLE C17: Analysis of variance for grain yield and protein for the seeding rate treatments.

Source	df	Grain yield	Grain protein
----- Mean squares -----			
Years (Y)	2	4861970	121.736
Landscape position (LP)	1	4875672*	1.628
Y*LP	2	255382*	8.197*
Replications	5	327980	1.423*
Treatment (T)	2	33165	0.039
Y*T	4	37113	0.322
LP*T	2	110949	0.809
Y*LP*T	4	35670	0.752
Error	85	259607	0.545

*significance level: .05

**significance level: .01

***significance level: .001

TABLE C18: Effect of seeding rate on grain yield across management units.

Landscape position	Grain yield (Kg ha ⁻¹)			
	1.0 Bu ac ⁻¹	1.5 Bu ac ⁻¹	2.0 Bu ac ⁻¹	Across Treatments
----- 1997 -----				
Upper Slope	1927	2100	2097	2042
Lower Slope	2578	2610	2655	2614
Column Mean	2253	2355	2376	2328
----- 1998 -----				
Upper Slope	2408	2442	2395	2415
Lower Slope	2956	2842	2828	2876
Column Mean	2682	2642	2612	2645
----- 1999 -----				
Upper Slope	2831	3116	2873	2940
Lower Slope	3163	3104	3278	3182
Column Mean	2997	3110	3076	3061

TABLE C19: Effect of seeding rate on grain protein across management units.

Landscape position	Grain protein (%)			Across Treatments
	1.0 Bu ac ⁻¹	1.5 Bu ac ⁻¹	2.0 Bu ac ⁻¹	
----- 1997 -----				
Upper Slope	16.1	16.1	16.3	16.1
Lower Slope	16.0	15.4	15.5	15.6
Column Mean	16.0	15.8	15.9	15.9
----- 1998 -----				
Upper Slope	13.1	12.7	13.3	13.0
Lower Slope	12.5	13.4	13.0	13.0
Column Mean	12.8	13.0	13.1	13.0
----- 1999 -----				
Upper Slope	11.8	11.7	11.9	11.8
Lower Slope	13.4	13.2	12.8	13.1
Column Mean	12.6	12.5	12.4	12.5

TABLE C20: Plant Available water over the growing season and across management units.

Landscape position	Plant available water (cm/0-30cm)				
	Spring	25 D.A.P.	50 D.A.P.	75 D.A.P.	Fall
1997					
Upper Slope	3.11	6.03	-0.80	-1.50	0.79
Lower Slope	5.08	2.22	0.79	-0.93	1.55
Column Mean	4.09	4.12	-0.01	-1.22	1.17
1998					
Upper Slope	1.26	0.00	2.91	0.37	0.67
Lower Slope	6.14	5.09	7.35	6.37	5.68
Column Mean	3.70	2.55	5.13	3.37	3.17
1999					
Upper Slope	2.30	1.54	2.52	-0.63	-0.41
Lower Slope	5.56	4.98	5.95	3.14	3.22
Column Mean	3.93	3.26	4.23	1.25	1.41

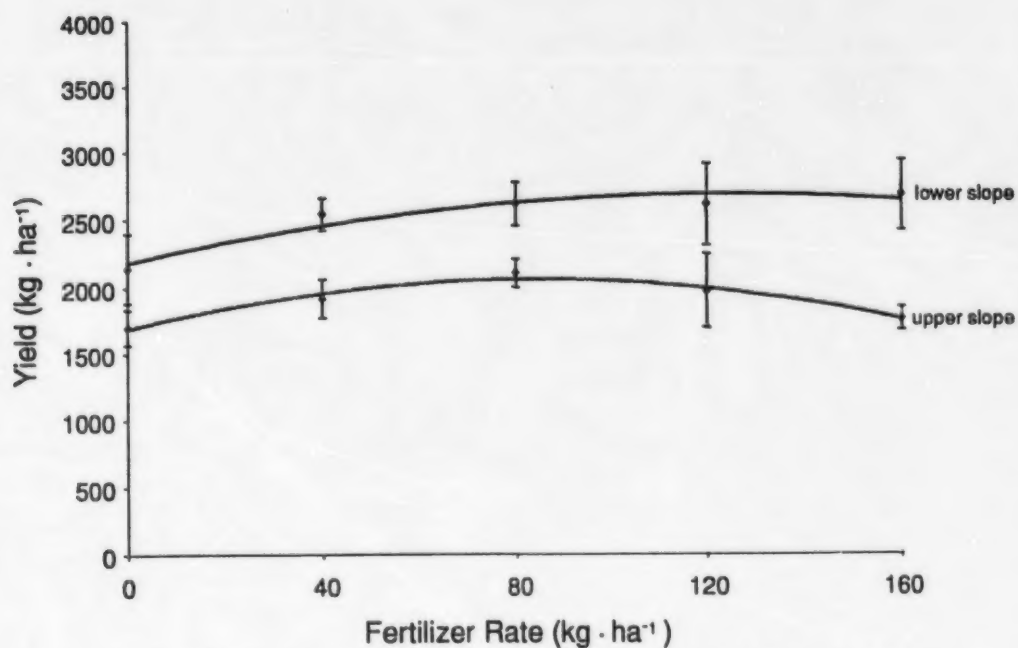


Figure C1: Fertilizer response curves, CLC (St. Louis) Wheat 1997

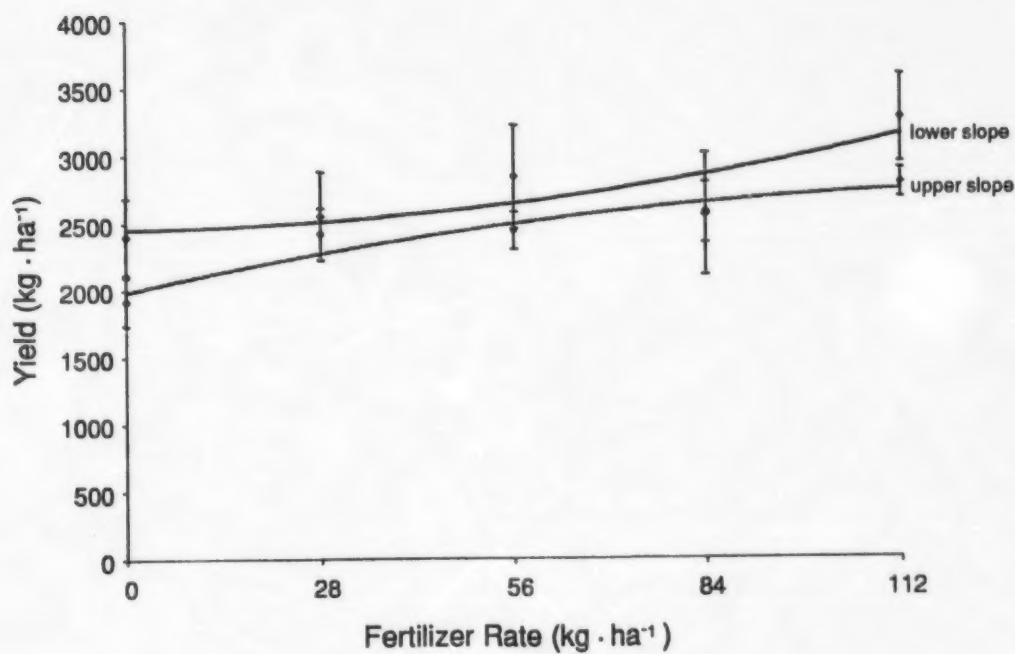


Figure C2: Fertilizer response curves, CLC (St. Louis) Wheat 1998

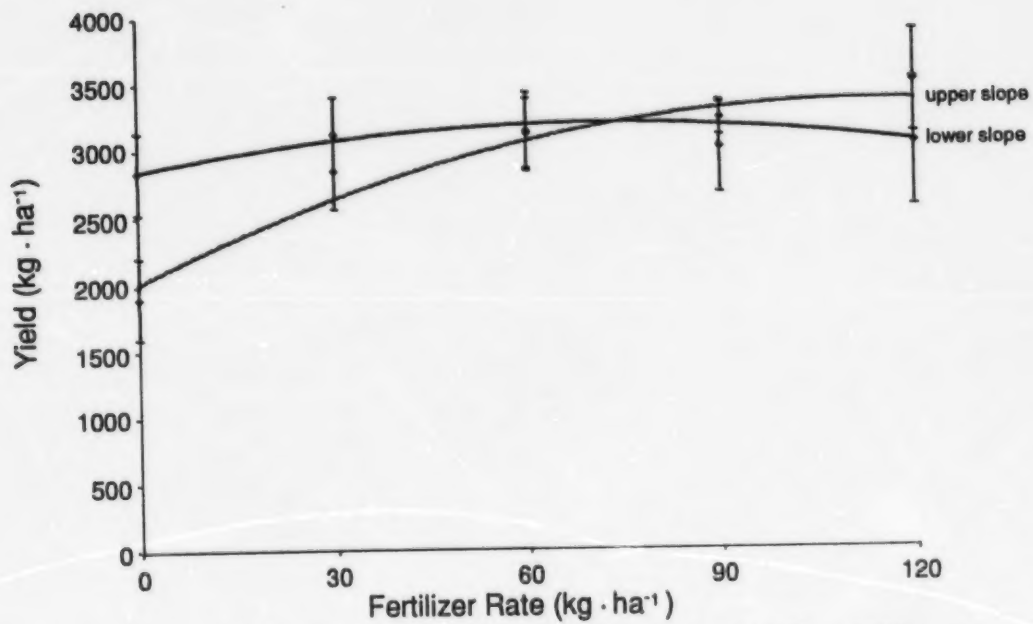


Figure C3: Fertilizer response curves, CLC (St. Louis) Wheat 1999

Swift Current

The Swift Current site is located on NE22-15-12W3. The site is mapped as a Haverhill 2 map unit. Haverhill soils are developed on medium textured glacial till parent materials and are moderately calcareous. The surface form of the site is slope class 5 hummocky, which is a typical surface form of glacial till surfaces throughout the province. The Swift Current site was managed by Dr. Brain McConkey of the Agriculture and Agri-Food Canada Research Station at Swift Current, Saskatchewan.

The distribution of soils at the Swift Current site is very similar to the soils at the other glacial till site (Watrous). The upper slopes are dominated by thin, organic-poor Orthic Regosolic soils (Table S1). The midslopes are dominated by Rego Chernozemic soils and the somewhat thicker Orthic Chernozemic soils. The lower slope units do not experience periodic water saturation in the drier Brown soil zone and hence instead of Gleysolic soils we found well-developed Eluviated Chernozemic soils in the lower slope units. A small area at the southern edge of the site had Solonetzic Brown Chernozemic soils in these lower slope positions.

The soil organic carbon levels in the management unit show a very typical increase from upper to lower slope units. The difference between upper and lower slope units is 28 Mg ha^{-1} . The SOC values also clearly indicate that the Swift Current site is the least productive of the sites – for example, the SOC contents of the lower slope soils at the CLC and Watrous sites are 121 and 132 Mg ha^{-1} , respectively, compared to only 74 Mg ha^{-1} at this site. Hence the Swift Current site has the most limited organic reservoir of our research sites.

The seeding date at Swift Current was similar in all three years of the study (Table S3). The growing season precipitation was below average for all three years of the study but was relatively well distributed throughout the growing season. No rainfalls in excess of 30 mm day⁻¹ were received throughout the study and hence flooding of the lower slope sites did not occur. The growing degree days for 1997 and 1998 were slightly above the normals for the region. Growing season temperatures were lower than average in 1999, especially for the first 25 days of the growing season.

The spring moisture conditions at the time of seeding were by far the highest in 1997. In 1997 there was no difference between the management units in terms of spring moisture (Table S4). By 1998 a significant landscape pattern had re-asserted itself, and the upper and midslope units were significantly drier than the lower slope units. Adequate levels of snowmelt recharge occurred in 1999, and again there was no difference between the management units at the time of seeding.

Spring N showed a consistent trend across management units for all three years of the study (Table S5). Generally the upper slopes had lower amounts of N than the lower slope units, but the absolute differences between units was small and generally not statistically significant. The range across management units for the three years of the study (i.e., from 20.5 kg ha⁻¹ in 1998 to 28.2 kg ha⁻¹ in 1999) was small compared to our other sites.

Nitrogen Treatments

For grain yield at Swift Current, year, management unit, and treatment were all significant factors, as were the interactions between year and management unit and

treatment and management unit (Table S6). Similar effects were seen for grain protein except that the management unit effect is not of significance for protein.

The effect of year on yields is due to the difference between the high yields achieved in 1997 and the lower yields in 1998 and 1999 (Table S7). The high yields in 1997 presumably reflect the very high spring moisture levels at the time of seeding. Protein levels were inversely related in yields in 1997 and 1998. In 1999, both the grain yields and protein levels were relatively low (compared to the other two years of the study). In 1999, the harvest index (averaged across N treatments) was only 0.33 compared to 0.45 in both 1997 and 1998. Hence the cooler temperatures experienced in 1999 meant that high biomass production relative to grain production occurred. A similar result was observed for 1999 at the Watrous site.

A highly significant management unit effect occurred across the three years of the study (Table S8). The greatest difference occurs between the upper slope unit and the mid and lower slope units. The difference between the upper and lower slope units was approximately 600 kg ha^{-1} . Compared to grain yield, grain protein was not influenced by landscape to the same extent.

The differences among the management units for grain yield were quite consistent across the three years of the study. In each year the difference between upper and lower units was 500 to 600 kg ha^{-1} . The midslope unit did not occupy a consistent position, with respect to yield, relative to the upper and lower units. In 1997 yields obtained in the midslope positions were similar to yields obtained in the lower slope positions; however, in 1998 yields obtained in the midslope positions were distinct from the other two management units, and in 1999 the yields were not statistically different from the rest of

the field. Hence it could be argued that the midslopes did not occupy a distinct productivity niche at this site and they could be simply divided between the upper and lower units.

Grain protein did not show a distinct relationship to management unit (Table S10). Hence whatever the landscape position control was on yield, it did not carry the same effect for grain protein.

Broadly similar responses to the five N treatments were seen for all three years of the study (Figure S1-3, Tables S11,12), although the actual yields differed among years as discussed above. In 1997, the yields at the 0N rate clearly differed between the three management units. The upper slope reached a distinct yield plateau at about the 1XN rate, followed by a decrease at higher rates. The N response curves for the midslope and lower slope units converged by the 0.5XN rate, and do not reach a distinct yield plateau. In 1998, the N response curves are separated throughout and the upper and midslope rates again reach a clear yield plateau. The lower slope function was essentially linear – no yield maximum was reached by the 2XN rate. In 1999, the three curves had similar intercepts at the 0N rate and overlap considerably up to the 1XN rate. The three curves separated at this point, and yield plateaus were reached for both the upper and midslope curves. The lower slope function was linear throughout its range.

The similarity in curves also caused a similarity in the economic analysis of the yield functions (Table S 13). For all three years, the optimum economic rate for the upper slope units was very close to the 1XN, soil test recommended rate. For the midslope and lower slope units, the economic optimum rate varied from 1.44XN to 1.70XN the recommended rate, and is generally very close to the 1.5XN rate. Hence the economic

analysis for the Swift Current site was relatively straightforward, and would indicate optimum rates of 1XN for the upper slopes and 1.5XN for the remainder of the field. The maximum economic net return to the VRF program (averaged across the three years of the study) was approximately \$12 ha⁻¹.

Phosphorus and Seeding Rate Treatments

The ANOVA for the P treatments indicates annual and landform position differences in yields but there was no evidence for a strong response to the different P treatments (Table S14). For all three years of the study there was a 200 to 300 kg ha⁻¹ increase in yield from the 0P to the 1P treatment, but only a slight increase or an actual decrease in yield for the 2P treatment. There was no clear protein response to the P treatments. The economics of the use of the 1P treatment are marginally favorable, but there was no rationale for higher than recommended P rates in any of the landform positions.

The same is true for the seeding rate treatments (Table S17). Again both year and landform position are very important for yield, but there was no treatment effect for seeding rate. The differences between the treatments in any year of the study were very small (Table S18).

Table S1: Distribution of soil subgroups in the management units. The subgroups are arrayed in approximate order from driest to wettest. These results are tabulated from the three years of the study.

Orders and Soil Subgroup	Upper Slope	Midslope	Lower Slope
<i>Regosolic</i>			
Orthic	33	9	1
<i>Chernozemic Dark Brown</i>			
Rego	8	11	4
Calcareous	1	7	3
Orthic	22	39	30
Solonetzic			8
Eluviated	3	4	30

Table S2: Mean soil organic carbon in the management units. These results are tabulated from the three years of the study.

Management Unit	Soil organic carbon. (Mg ha ⁻¹)
Upper	46.1 ^a
Mid	58.6 ^b
Lower	74.0 ^c
<i>Grand mean</i>	59.7

Table S3: Growing season climate statistics; precipitation, growing degree days, and significant events.

Site	Seeding Date	Seeding to 25DAP	26DAP to 50DAP	51DAP to 75DAP	76DAP to Harvest	Growing Season Precipitation	Growing Degree Days (base 5°C)
----- Precipitation (mm) -----							
1997	May 1	50.3	61.7	22.3	48.7	183.0 ¹	1356
1998	May 6	33.7	41.3	71.3	26.1	172.4	1454
1999	May 19	61.1	46.5	26.3	2.6	139.5	1253
30 year average ²						205.4	1273
Significant Events							
Date	Frost (Minimum Temperature C)			Precipitation Greater than 20mm			
1997	May 1	-1.5		May 23	26.0		
	May 2	-3.0		June 6	27.4		
	May 3	-1.9					
	May 8	-2.5					
	May 11	-1.6					
	May 14	-2.0					
	May 18	-0.9					
	May 20	-0.9					
1998	May 7	-2.4					
	May 8	-1.7					
	May 13	-2.6					
	June 1	-0.1					
	June 2	-0.2					
1999	June 3	-0.7					
	September 9	-0.6		June 3	24.6		
	September 13	-0.4					
	September 14	-3.2					

¹Total Precipitation-Seeding to Harvest.

²30 year averages, May 1 – September 31, obtained from the nearest Environment Canada Meteorological Station.

Table S4: Plant available water; pre-seeding.

Landscape Position	1997	1998	1999	Across years
	----- <i>cm available water per 90 cm soil</i> -----			
Upper	7.05 ^a	0.71 ^a	3.83 ^a	4.32 ^a
Mid	5.79 ^a	0.80 ^a	3.97 ^a	3.94 ^a
Lower	6.33 ^a	5.15 ^b	3.90 ^a	5.30 ^a
Grand mean	6.39	2.28	3.90	4.53

Table S5: Soil nitrate; pre-seeding.

Landscape Position	1997	1998	1999	Across years
	----- <i>Kg ha⁻¹ to 60 cm</i> -----			
Upper	18.8 ^a	17.1 ^a	15.1 ^a	18.0
Mid	26.8 ^b	19.9 ^{ab}	37.4 ^a	25.1
Lower	33.0 ^c	24.5 ^b	32.2 ^a	29.9
Grand mean	26.1	20.5	28.2	24.3

Table S6: Analysis of variance for grain yield and protein for the N treatments.

Source	df	Grain yield	Grain protein
		----- <i>Mean squares</i> -----	
Years (Y)	2	2100989*	60.8673**
Landscape position (LP)	2	4719014**	4.5508
Y*LP	4	249204**	1.8910*
Replications	2	441418	3.2015**
Treatment (T)	4	5762802***	25.1110**
Y*T	8	90555	3.4261***
LP*T	8	252807***	1.3741*
Y*LP*T	16	41492	0.4278
Error	88	151926	0.6382

*significance level: .05

**significance level: .01

***significance level: .001

Table S7: Mean grain yield and protein averaged across treatments and landscape position.

Year	Grain yield (kg ha ⁻¹)	Grain protein (%)
1997	1762 ^a	10.0 ^a
1998	1333 ^b	12.1 ^b
1999	1317 ^b	10.8 ^c
<i>Grand mean</i>	1501	11.0

Table S8: Mean grain yield and protein averaged across years and treatments.

Year	Grain yield (kg ha ⁻¹)	Grain protein (%)
Upper	1164 ^a	11.3 ^a
Mid	1557 ^b	11.0 ^{ab}
Lower	1782 ^c	10.7 ^a
<i>Grand mean</i>	1501	11.0

Table S9: Mean spring grain yield averaged across N treatments.

Landscape Position	1997	1998	1999
	<i>Kg ha⁻¹</i>		
Upper	1403 ^a	968 ^a	1080 ^a
Mid	1902 ^b	1312 ^b	1359 ^{ab}
Lower	1980 ^b	1718 ^c	1513 ^b
<i>Grand mean</i>	1762	1333	1317

Table S10: Mean spring grain protein averaged across N treatments.

Landscape Position	1997	1998	1999
	<i>%</i>		
Upper	10.5 ^a	12.4 ^a	10.8 ^a
Mid	9.9 ^b	12.0 ^a	11.1 ^{ab}
Lower	9.8 ^b	11.9 ^a	10.4 ^b
<i>Grand mean</i>	10.0	12.1	10.8

Table S11: Effect of N fertilizer rate on grain yield across management units.

Landscape position	Grain Yield (Kg ha ⁻¹)				
	0N1P	0.5N1P	1N1P	1.5N1P	2N1P
-----1997-----					
Upper Slope	709	1257	1806	1696	1548
Midslope	928	1717	2132	2282	2449
Lower Slope	1313	1680	2021	2463	2424
Column Mean	983	1551	1986	2147	2140
-----1998-----					
Upper Slope	529	802	1144	1124	1241
Midslope	738	1012	1546	1564	1701
Lower Slope	915	1171	1862	2148	2495
Column mean	727	995	1517	1612	1812
-----1999-----					
Upper Slope	524	942	1255	1559	1121
Midslope	760	998	1394	2010	1632
Lower Slope	822	1133	1421	2088	2100
Column Mean	702	1024	1357	1886	1617

Table S12: Effect of N fertilizer rate on grain protein across management units.

Landscape position	Grain Protein (%)				
	0N1P	0.5N1P	1N1P	1.5N1P	2N1P
-----1997-----					
Upper Slope	9.1	8.7	9.9	11.5	13.0
Midslope	9.0	8.7	9.2	10.5	11.9
Lower Slope	9.2	8.8	9.2	10.1	11.5
Column Mean	9.1	8.8	9.4	10.7	12.1
-----1998-----					
Upper Slope	11.0	10.8	12.4	13.8	14.3
Midslope	11.7	11.1	11.6	12.8	13.0
Lower Slope	11.6	11.3	11.8	12.2	12.7
Column mean	11.4	11.1	11.9	12.9	13.3
-----1999-----					
Upper Slope	10.8	10.5	10.6	10.7	11.6
Midslope	11.5	10.1	11.1	11.3	11.8
Lower Slope	10.1	10.3	10.3	10.2	10.8
Column Mean	10.8	10.3	10.7	10.7	11.4

Table S13: Economic Optima Nitrogen Rates and Net Returns. Calculations assume N@\$0.587 kg⁻¹ and wheat@\$0.11043 kg⁻¹ for a price ratio of 5.3156.

Unit	N Rate at Economic Optima ----- Kg ha ⁻¹ -----	Yield at Economic Optima -----	Net Return at Economic Optima ----- \$ ha ⁻¹ -----	Minus Net Return at 1X Rate
-----1997-----				
Upper	62 (1.11X) ¹	1734.7	155.17	0.74
Mid	84 (1.50X)	2370.1	212.43	11.51
Lower	98 (1.75X)	2418.3	209.52	12.51
Entire Field ²				8.25
-----1998-----				
Upper	57 (1.02X)	1147.5	93.26	0.01
Mid	87 (1.44X)	1751.7	142.37	8.02
Lower	85 (1.52X)	2287.4	202.71	13.30
Entire Field				7.11
-----1999-----				
Upper	50 (1.11X)	1361.4	120.99	0.85
Mid	69 (1.53X)	1716.6	149.06	9.32
Lower	90 (1.61X)	2215.3	192.04	51.28
Entire Field				20.48

¹N rate at economic optima as a fraction of entire-field recommended rate.

²Entire-field return calculated assuming equal proportions of the three units in the field.

Table S14: Analysis of variance for grain yield and protein for the P treatments.

Source	df	Grain yield	Grain protein
----- Mean squares -----			
Years (Y)	2	3720665**	57.265***
Landscape position (LP)	2	1583905*	3.257
Y*LP	4	205481*	0.716
Replications	2	261491	2.256
Treatment (T)	2	298670	0.877
Y*T	4	56068	0.933
LP*T	4	50689	0.421
Y*LP*T	8	41259	0.255
Error	52	98155	1.013

*significance level: .05

**significance level: .01

***significance level: .001

Table S15: Effect of P fertilizer rate on grain yield across management units.

Landscape position	Grain yield (Kg ha ⁻¹)			
	0P1N	1P1N	2P1N	Across Treatments
----- 1997 -----				
Upper Slope	1475	1806	1947	1743
Midslope	1849	2132	2158	2046
Lower Slope	2034	2021	2128	2061
Column Mean	1786	1986	2078	1950
----- 1998 -----				
Upper Slope	715	1144	1010	956
Midslope	1288	1546	1398	1410
Lower Slope	1588	1862	1555	1668
Column Mean	1197	1517	1321	1345
----- 1999 -----				
Upper Slope	1096	1255	1054	1135
Midslope	1091	1394	1420	1302
Lower Slope	1246	1421	1325	1331
Column Mean	1144	1357	1266	1256

Table S16: Effect of P fertilizer rate on grain protein across management units.

Landscape position	Grain protein (%)			
	0P1N	1P1N	2P1N	Across Treatments
1997				
Upper Slope	11.1	9.9	9.6	10.2
Midslope	10.3	9.2	9.4	9.6
Lower Slope	9.7	9.2	9.1	9.3
Column Mean	10.4	9.4	9.4	9.7
1998				
Upper Slope	13.1	12.4	12.7	12.7
Midslope	12.5	11.6	12.0	12.0
Lower Slope	11.6	11.8	11.5	11.6
Column Mean	12.4	11.9	12.1	12.1
1999				
Upper Slope	10.3	10.6	10.3	10.4
Midslope	10.4	11.1	10.9	10.8
Lower Slope	10.2	10.3	10.0	10.2
Column Mean	10.3	10.7	10.4	10.5

Table S17: Analysis of variance for grain yield and protein for the seeding rate treatments.

Source	df	Grain yield	Grain protein
----- Mean squares -----			
Years (Y)	2	3299421***	60.1940***
Landscape position (LP)	2	1321069***	2.5339
Y*LP	4	139519	1.0669
Replications	2	142950	1.4195
Treatment (T)	2	51045	0.0791
Y*T	4	54632	0.2078
LP*T	4	21483	0.3666
Y*LP*T	8	34812	0.1084
Error	52	111278	0.9991

*significance level: .05

**significance level: .01

***significance level: .001

Table S18: Effect of seeding rate on grain yield across management units.

Landscape position	Grain yield (Kg ha ⁻¹)			Across Treatments
	1.0 Bu ac ⁻¹	1.5 Bu ac ⁻¹	2.0 Bu ac ⁻¹	
----- 1997 -----				
Upper Slope	1851	1806	1947	1868
Midslope	1994	2132	2158	2095
Lower Slope	2192	2021	2128	2114
Column Mean	2012	1986	2078	2025
----- 1998 -----				
Upper Slope	1136	1144	1010	1096
Midslope	1423	1546	1398	1455
Lower Slope	1518	1862	1555	1645
Column Mean	1359	1517	1321	1399
----- 1999 -----				
Upper Slope	1250	1255	1054	1186
Midslope	1593	1394	1420	1469
Lower Slope	1441	1421	1325	1396
Column Mean	1428	1357	1266	1350

Table S19: Effect of seeding rate on grain protein across management units.

Landscape position	Grain protein (%)			
	1.0 Bu ac ⁻¹	1.5 Bu ac ⁻¹	2.0 Bu ac ⁻¹	Across Treatments
<i>----- 1997 -----</i>				
Upper Slope	10.0	9.9	9.6	9.8
Midslope	9.8	9.2	9.4	9.5
Lower Slope	9.5	9.2	9.1	9.3
Column Mean	9.8	9.4	9.4	9.5
<i>----- 1998 -----</i>				
Upper Slope	12.4	12.4	12.7	12.5
Midslope	11.8	11.6	12.0	11.8
Lower Slope	12.1	11.8	11.5	11.8
Column Mean	12.1	11.9	12.1	12.0
<i>----- 1999 -----</i>				
Upper Slope	10.5	10.6	10.3	10.5
Midslope	11.1	11.1	10.9	11.0
Lower Slope	10.1	10.3	10.0	10.1
Column Mean	10.6	10.7	10.4	10.6

Table S20: Plant Available water over the growing season and across management units.

Landscape position	Plant available water (cm/0-30cm)				
	Spring	25 D.A.P.	50 D.A.P.	75 D.A.P.	Fall
1997					
Upper Slope	2.49	1.70	0.61	-1.61	-0.06
Midslope	2.21	1.69	0.03	-1.32	-0.44
Lower Slope	2.83	1.62	-0.17	-2.07	-0.94
Column Mean	2.51	1.67	0.16	-1.67	-0.48
1998					
Upper Slope	0.38	0.36	0.85	-0.41	-0.82
Midslope	0.71	1.16	1.25	-0.23	-0.52
Lower Slope	2.04	1.97	1.78	-0.01	-0.83
Column Mean	1.04	1.16	1.29	-0.22	-0.72
1999					
Upper Slope	1.98	2.14	2.72	-1.02	-2.29
Midslope	2.46	2.97	2.18	-0.27	-1.90
Lower Slope	2.41	2.84	2.17	-0.43	-1.96
Column Mean	2.28	2.65	2.36	-0.57	-2.05

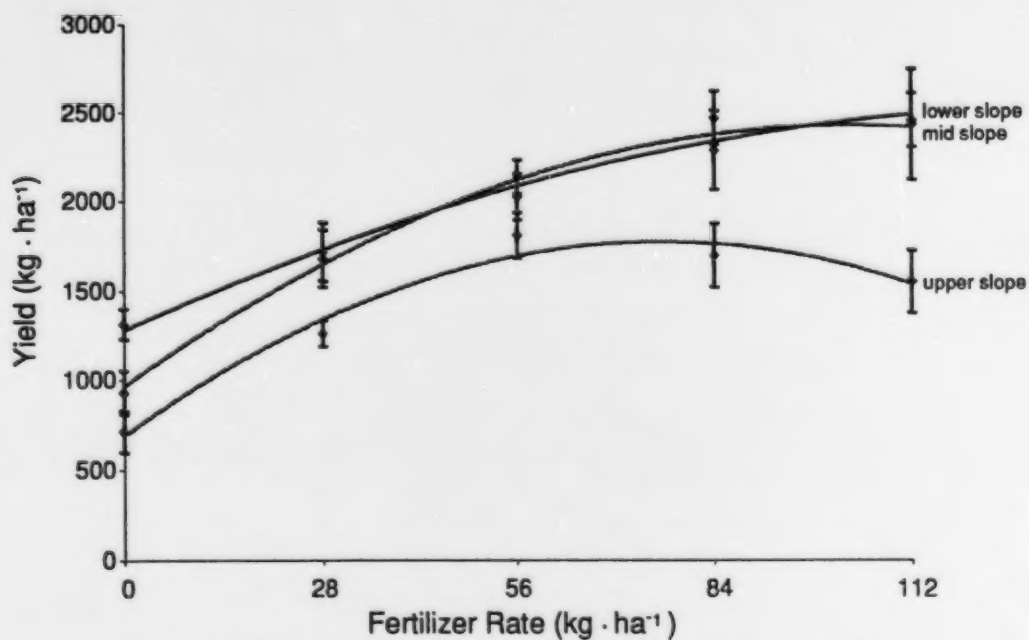


Figure S1: Fertilizer response curves, Swift Current Wheat 1997

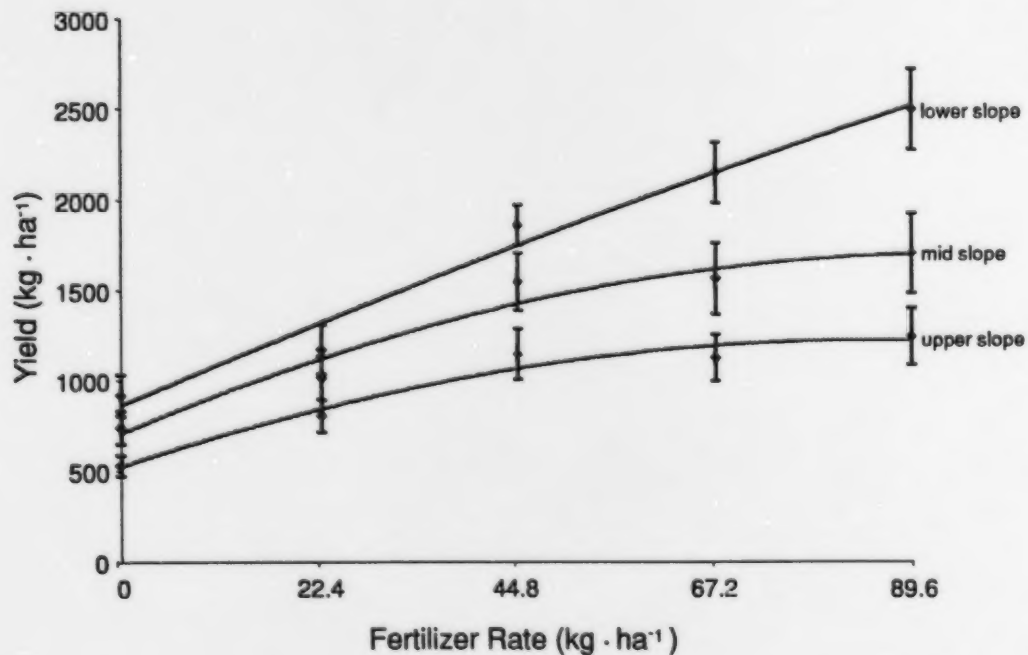


Figure S2: Fertilizer response curves, Swift Current Wheat 1998

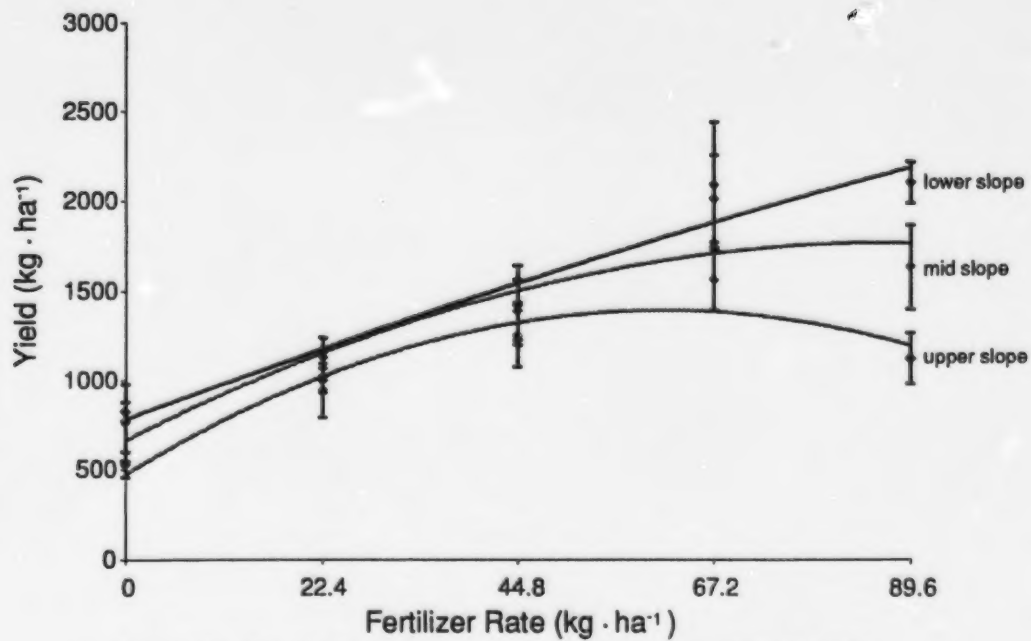


Figure S3: Fertilizer response curves, Swift Current Wheat 1999

Summary and Conclusions

Research on the yield and protein response of spring wheat to variable rate treatments of nitrogen, phosphorus, and seeding rate was carried out at four sites in Saskatchewan:

1. A hummocky glacial till site in the Brown soil zone near Swift Current,
2. A hummocky glacial till site in the Dark Brown soil zone near Watrous,
3. An irrigated undulating glaciolacustrine site in the Dark Brown soil zone near Outlook, and
4. A hummocky glaciolacustrine site in the thick black soil zone near St. Louis.

The same basic research design was used at all four sites. Each year of the study (1997, 1998, and 1999) a composite soil sample was taken before seeding and a soil test recommended rate for N and P was determined following standard soil testing procedures. Five N rates were used (0, 0.5, 1, 1.5 and 2X the recommended rates) and three P rates (0, 1, and 2X the recommended rates), as well as an absolute control (0N0P). Three seeding rates were also used: 1.0, 1.5, and 2.0 bu ac⁻¹. The set of 10 treatments was randomized in blocks. Each set of blocks spanned the full range of management units (upper, mid, and lower slope units) present at the site and were replicated six times. In subsequent years the sets of blocks were moved to adjacent parts of the field so there would be no carry-over of fertility between the years of the study. The crop was harvested with a small-plot combine in 10-m long strips. Protein was subsequently determined for a grain sample from each sampled strip.

The effect that landscape position exerted on soil productivity was related to the glacial history of the sites. Generally, the variability in soil productivity and soil organic matter content was greater at the glacial till sites (Watrous, Swift Current), as compared to the glaciolacustrine sites (CLC, Outlook). Grain yield showed a distinct and statistically significant relationship to the three management units at the two glacial till sites. Overall, yields at these two sites were lowest in the upper slope positions and increased downslope. Alternatively, grain yields were not clearly associated with landscape position at the two glaciolacustrine sites. In both cases, the soil moisture differences between the management units at the time of seeding were limited – at outlook due to irrigation and at the CLC due to higher precipitation and snowmelt recharge which is characteristic to the thick Black soil zone.

Generally, grain protein content was inversely related to grain yield, that is, the higher the yield the lower the grain protein. This relationship did not hold, however, for two sites in 1999 where high spring soil moisture, late seeding dates, and below average growing degree days resulted in high biomass production and relatively low harvest index values. Furthermore, grain protein did not show a consistent relationship across management units at any of the sites. This indicates that whatever factor(s) controlled grain yield differences between management units did not exert a similar influence on grain protein.

No consistent evidence exists that suggests that an economic advantage, for either grain yield or protein, can be realized by preferentially applying fertilizer N to upper slope units. Although the upper slope units were less fertile, as compared to the lower

slope units (as seen by lower available spring N levels), the major limitation to crop growth was moisture. This moisture limitation could not be overcome with higher fertilizer N additions. The greatest potential for increased yields, through higher N fertilizer additions, occurred in the lower slope units, provided that they were at average or above average soil moisture content at the time of seeding. These units, however, were also more susceptible to flooding after major rainfall events. We concluded that, although the lower slope positions were the most responsive to fertilization, they also were the most likely to suffer yield losses due to adverse growing conditions (flooding, weed pressure, and occurrence of disease).

Variable rate P fertilization or seeding rate did not hold any potential at any of the sites. There was no evidence of a fertilizer P response above the recommended rate; furthermore, P did not show a management-unit-specific response. No consistent differences, in either grain yield or protein, were observed for seeding rate treatments.

The net economic return to an optimum variable rate N fertilization program was calculated for each year of the study at each site. The calculations were based on a retrospective economic assessment (i.e., perfect hindsight) of the management unit-specific yield functions for the N treatments for each year. The returns were calculated relative to a constant 1XN (i.e., soil test recommended rate) at the site. The net return to the producer (averaged over the three years of the study) of the optimum variable rate (VR) N rates was \$2.50 ha⁻¹ at Outlook, \$15 ha⁻¹ at Watrous, \$12 ha⁻¹ at Swift Current, and \$12 ha⁻¹ at the St. Louis (CLC) site. Note that these returns are based on a price of N fertilizer at \$0.587 kg⁻¹ and a price of wheat at \$0.11043 kg⁻¹ and will change as the price of either commodity changes. As well, these represent the maximum possible return of

the VR N scenario and are unlikely to be achieved by producers based on the information available to them at the time of seeding.

A comparison of three popular yield monitors and GPS receivers was completed by the Prairie Agricultural Machinery Institute. The yield monitor tests showed that all three yield monitors assessed gave results within $\pm 3\%$ of actual yields if at least four loads of each type of grain were independently weighed to provide calibration values. This requires that producers have access to an accurate scale during calibration, and also involves a time commitment at harvest. The GPS systems tested generally provided locations within 1 m of the actual location of the combine. The combination of the yield measurement and GPS location in the mapping software is subject to further errors associated with machine lag time. The yield at each location on the resulting yield map may be shifted by 7 to 8 m depending on the size of equipment.

Micronutrients Levels and Relationship to Management Units at the AFIF Sites

This section was prepared by Dr. Diane Knight of the Saskatchewan Center for Soil research.

Methodology:

Micronutrient levels (Cu, Fe, Mn, Zn, and B) were determined, at each of the AFIF research sites, for the 1998 crop year. Only the treatment receiving the recommended rate of nitrogen fertilizer and no phosphorous fertilizer (1N, 0P) was sampled in each block for subsequent micronutrient analyses. Soils from each management unit were spring sampled at 3 depths: 0–15 cm; 15–30 cm; and 30–60 cm. Plant available Cu, Fe, Mn and Zn were extracted with DTPA-extractant and quantified using atomic absorption spectrometry. Plant available B was extracted by hot water extraction and quantified spectrophotometrically.

A preliminary statistical analysis revealed that none of the micronutrients at any depth were normally distributed; i.e., they all had a high degree of skewness. Consequently, the data were analyzed using non-parametric procedures and only the median values are presented. Data were analyzed using the Friedman two-way analysis of variance by ranks. Data were compared to the critical levels of micronutrients for farm soils used by Enviro-Test laboratories in Saskatoon (Table MN1).

Table MN1: Critical Micronutrient Levels for Farm soils (Enviro-Test Laboratories, 1999).

Nutrient	Concentration ($\mu\text{g g}^{-1}$)			
	Deficient	Marginal	Optimum	High
B (0-6") low B-using crops	<0.25	0.25-0.5	0.5-3.5	+3.5
high B-using crops	<0.35	0.35-0.6	0.6-3.5	+3.5
Cu (0-6")	<0.60	0.6-1.0	1.0-8.0	+8.0
Fe (0-6")	<2.50	2.5-4.5	4.5-150.0	+150.0
Mn (0-6")	<0.50	0.5-1.0	1.0-20.0	+20.0
Zn (0-6")	<0.25	0.25-0.5	0.5-7.5	+7.5

Conservation Learning Centre

All concentrations of B, Fe, and Mn were in the optimal range (Table 1) regardless of slope position or depth (Table MN2). Even though there was a slope position effect for B (0-30 cm) and Fe (15-60 cm), with both of these micronutrients accumulating in the lower slope units, this was of little consequence for variable rate fertilization because these soils contained sufficient levels of these micronutrients. Zinc concentrations were optimal at the surface but declined to marginal levels deeper in the soil. Zinc concentrations dropped more sharply with depth in the upper slope units than in the lower slope units (i.e., concentrations dropped to marginal levels in the 15-30 cm layer in the upper slope units but did not drop to marginal concentrations until the 30-60 cm depth in the lower slope units). The optimal Zn concentrations in the surface soils were probably sufficient to support a crop throughout the 1998 growing season, however the sharp drop in concentration with depth in the upper slope units might indicate a potential for preferential Zn fertilization in these slope units. Copper concentrations at this site were all in the marginal to deficient range; however, there was no slope unit

effect on distribution. Because of the relatively high organic matter content, and neutral pH, which tend to immobilize Cu, soils in the Thick Black soil zone represent the category of mineral soils with a high potential for Cu deficiency developing. Although this site could probably benefit from a general application Cu fertilizer, the lack of a slope unit effect on Cu distribution indicates no potential for the implementation of a variable rate fertilization program for this micronutrient.

Table MN2: Conservation Learning Centre. Median concentrations of plant available forms of micronutrients.

Slope position	Sampling depth	-----Micronutrient ($\mu\text{g g}^{-1}$)-----				
		B	Cu	Fe	Mn	Zn
Lower	0-15cm	1.65	0.58	65.80	22.61	4.70
	15-30cm	1.79	0.75	84.20	11.91	5.08
	30-60cm	0.86	0.74	40.85	8.14	0.30
Mid	0-15cm	n/a ¹	n/a	n/a	n/a	n/a
	15-30cm	n/a	n/a	n/a	n/a	n/a
	30-60cm	n/a	n/a	n/a	n/a	n/a
Upper	0-15cm	0.93	0.50	41.80	15.71	1.12
	15-30cm	1.01	0.58	17.10	5.24	0.27
	30-60cm	1.10	0.97	13.15	3.35	0.28
-----Probability of response to slope unit ² -----						
	0-15cm	0.014	0.535	0.102	0.102	0.014
	15-30cm	0.014	0.414	0.014	0.102	0.025
	30-60cm	0.414	1.000	0.014	0.414	1.000

¹Not applicable; no mid-slope positions at this site

²Determined from Friedman two-way analysis of variance by ranks

Outlook

As was the case at the Conservation Learning Centre, all concentrations of B, Fe, and Mn were in the optimal range (Table MN1). Each of these micronutrients were

concentrated in the surface 0-30 cm (Table MN3). However, the optimal concentrations that were present indicated that fertilization was not necessary at this site. Copper concentrations ranged from marginal to optimal, with a tendency for levels to increase with depth. Increasing concentrations with depth tend to indicate a low probability of a deficiency developing because as a crop grows roots explore deeper and deeper soil volumes. Only in wet growing seasons, when roots tend to remain near the soil surface, would a distribution profile with low to marginal concentrations at the surface and higher concentrations deeper in the soil pose any potential problem. A slope unit effect for Cu did exist at this site, with Cu concentrated in the upper slope units in the surface soils. The marginal Cu concentrations in the surface soils of the lower and mid slope units could indicate the potential for Cu deficiencies to develop in these slope units in wet years compared to dry years. These slope units might benefit from applications of Cu fertilizer. Zinc concentrations tended to be in the optimal range, particularly in the surface 30 cm. There were opposing slope unit effects on Zn distribution in the 0-15 cm and 30-60 cm depths in that Zn accumulated in the surface layer in the lower slope units whereas in the upper slope units the highest accumulations were at the 30-60 cm depth. Because of the difficulty with predicting slope unit effects on distribution and the generally optimal concentrations of Zn in the soils, it is unlikely that Zn deficiencies would develop at this site or that variable rate applications would be effective.

Table MN3: Outlook. Median concentrations of plant available forms of micronutrients.

Slope unit	Sampling depth	-----Micronutrient ($\mu\text{g g}^{-1}$)-----				
		B	Cu	Fe	Mn	Zn
Lower	0-15cm	1.14	0.67	18.40	20.12	1.05
	15-30cm	0.94	0.75	14.27	5.33	0.60
	30-60cm	0.88	1.58	12.90	4.64	0.42
Mid	0-15cm	0.92	0.65	13.63	18.97	0.61
	15-30cm	0.71	1.30	11.20	4.52	0.53
	30-60cm	0.56	1.93	12.30	5.12	0.34
Upper	0-15cm	0.75	1.13	10.37	11.72	0.60
	15-30cm	0.61	0.86	12.83	5.17	0.50
	30-60cm	0.59	2.40	15.40	6.37	0.54
		-----Probability of response to slope unit ¹ -----				
	0-15cm	0.030	0.030	0.010	0.042	0.011
	15-30cm	0.115	0.009	0.115	0.311	0.130
	30-60cm	0.115	0.135	0.030	0.115	0.012

¹ Determined from Friedman two-way analysis of variance by ranks

Swift Current

This site had optimal levels (Table MN1) of all of the micronutrients analysed except B (Table MN4). Thus, even though Fe distribution was related to the slope unit, the high concentration for all depths across the landscape preclude the need for applications of Fe fertilizer. Slope unit also affected B distribution. Overall, B accumulated in the lower slope positions and was more concentrated in the surface layer of all of the slope units. Of all of the micronutrients tested, B is the most water soluble and is expected to distribute according to the flow of water, hence, accumulating in lower slope units. However, on the same basis it is surprising that the highest concentration was in the surface soil as B would be expected to leach through the soil profile. Boron concentrations were optimal throughout the soil profile in the lower slope units.

However, in the mid and upper slope units concentrations were marginal in the surface soil and deficient below a 15 cm depth. These deficient B concentrations deep in the soil indicate a fairly high potential for a B deficiency developing, particularly in high B using crops like canola or alfalfa. Yield reductions related to B deficiency are more likely to occur at this site in dry years when crops root deeply in the soil. Application of B fertilizer to only the mid and upper slopes could be a feasible management strategy at this site.

Table MN4: Swift Current. Median concentrations of plant available forms of micronutrients.

Slope unit	Sampling depth	-----Micronutrient ($\mu\text{g g}^{-1}$)-----				
		B	Cu	Fe	Mn	Zn
Lower	0-15cm	0.81	1.14	22.13	12.98	1.49
	15-30cm	0.57	1.80	24.47	9.81	1.02
	30-60cm	0.64	1.42	23.2	10.46	1.03
Mid	0-15cm	0.47	1.04	15.50	11.06	1.09
	15-30cm	0.24	1.19	16.50	5.54	0.78
	30-60cm	0.25	1.38	14.8	6.14	0.85
Upper	0-15cm	0.40	0.94	21.37	10.50	1.24
	15-30cm	0.15	1.14	19.53	6.58	1.06
	30-60cm	0.21	1.19	15.3	7.05	0.93
		-----Probability of response to slope unit ¹ -----				
	0-15cm	0.042	0.115	0.030	0.115	0.453
	15-30cm	0.030	0.115	0.069	0.115	0.044
	30-60cm	0.042	0.311	0.223	0.846	0.311

¹ Determined from Friedman two-way analysis of variance by ranks

Watrous

Concentrations of Cu, Fe, and Mn were optimal (Table MN1) throughout the depth profile across the landscape indicating no need for amending soils with these

micronutrients (Table MN5). Zinc concentrations were optimal in the 0-15 cm increment, but were marginal from 15-60 cm. However, the distribution of Zn was not affected by slope unit indicating that variable rate application of Zn fertilizer has no immediate potential at this site. Overall, even though some marginal levels were detected, because of the fairly high concentrations of Zn at the surface, it is unlikely crops would have responded to any Zn fertilization at this site. Boron concentrations showed a similar distribution pattern to Zn. There was no effect of slope unit on B distribution, precluding any potential advantage to variable rate applications of B fertilizers. Boron concentrations were optimal in the surface layers and tended to decrease to the marginal range in the 15-30 cm and 30-60 cm layers. As was the case with Zn, the optimal concentrations at the surface are probably sufficient to supply a crop throughout the growing season, making B fertilization unnecessary at this site.

Table MN5: Watrous. Median concentrations of plant available forms of micronutrients.

Slope unit	Sampling depth	-----Micronutrient ($\mu\text{g g}^{-1}$)-----				
		B	Cu	Fe	Mn	Zn
Lower	0-15cm	1.13	1.19	30.60	17.72	1.69
	15-30cm	0.44	1.64	34.00	8.28	0.32
	30-60cm	0.59	2.01	37.35	7.065	0.25
Mid	0-15cm	0.92	1.29	28.60	18.53	1.05
	15-30cm	0.59	1.82	30.70	10.88	0.30
	30-60cm	0.38	2.12	28.55	9.89	0.28
Upper	0-15cm	0.81	1.53	26.40	13.59	0.67
	15-30cm	0.77	2.28	24.00	9.29	0.24
	30-60cm	0.84	2.16	23.05	7.82	0.28
		-----Probability of response to slope unit ¹ -----				
		0-15cm	0.223	0.135	0.846	0.513
		15-30cm	0.115	0.223	0.115	0.846
		30-60cm	0.115	0.846	0.607	0.513

¹ Determined from Friedman two-way analysis of variance by ranks

Summary and Conclusions

In general, variable rate applications of micronutrient fertilizers showed very little widespread potential. For the most part, none of the micronutrient distributions were predictably affected by slope unit. Even B, which is very water soluble, did not consistently accumulate in lower slope units as might be expected. More importantly, it is very unlikely that widespread micronutrient deficiencies will develop in Saskatchewan soils, so that fertilization of any type (variable or uniform application) will not be necessary. The three exceptions were a limited potential for Zn deficiency developing at the Conservation Learning Centre site, a fairly high potential for Cu deficiency developing at the Conservation Learning Centre site, and a fairly high potential for B deficiency developing at the Swift Current site. Zinc was the one micronutrient that tended to approach marginal levels at all of the sites except Swift Current. The relatively strong slope unit effect at the Conservation Learning Centre indicates some potential for variable rate application of Zn fertilizer at this site. Low plant available Cu at the Conservation Learning Centre is not terribly surprising as soils in this area possess characteristics (relatively high organic matter and pH) that reduce Cu availability to plants. These soils were uniformly low in Cu and would exhibit no benefit from variable rate applications of Cu fertilizer. The low B levels at the Swift Current site were unexpected. Boron is very water soluble and thus easily leached, it is also strongly adsorbed to organic matter especially in acid to neutral pH soils. Thus its availability would be expected to be lower in regions in the Dark Brown or Black soil zones, that receive more moisture and have higher organic matter contents, than dry regions in the Brown soil zone where Swift Current is located. Nonetheless, based on B concentrations

and distributions through the soil profile the Swift Current site did appear to have a high potential for B deficiencies developing in crops especially in the mid and upper slope units. Variable rate applications of B fertilizer might prove effective.

Equipment Evaluation

A comparison of three popular yield monitors and GPS receivers was completed by the Prairie Agricultural Machinery Institute. The results of this work were published as PAMI Research Update 745 in October 1999. A copy of this report is appended to our report, and will only be briefly summarized here.

The yield monitor tests showed that all three yield monitors assessed gave results within $\pm 3\%$ of actual yields if at least four loads of each type of grain were independently weighed to provide calibration values. This requires that producers have access to an accurate scale during calibration, and also involves a time commitment at harvest. The GPS systems tested generally provided locations within 1 m of the actual location of the combine. The combination of the yield measurement and GPS location in the mapping software is subject to further errors associated with machine lag time. The yield at each location on the resulting yield map may be shifted by 7 to 8 m depending on the size of equipment. Refer to the attached PAMI Research Update (#745) for further information.

Information on Project Sharing

From the outset the AFIF project was designed to deliver timely information to the "front-end" extension workers. The role of the university and co-operating researchers is to develop and evaluate the data produced from the field research, and then deliver this information to the field staff. Information was delivered through a number of different venues including conferences, workshops, and field days. A research bulletin, produced by PAMI (#745), on combine-mounted yield monitors was also compiled (Appendix 1).

The specific extension activities that were carried out over the duration of the project are listed in chronological order below.

Field Days

Title: Swift Current Field

Date: July 3, 1997

Audience: 275 producers and agriculture industry representatives

Organized by: SPARC, SSCA, and Wheatlands Conservation Area

Presented by: F. Walley

Title: AFIF Field Day (Watrous and Outlook experimental sites)

Date: July 15, 1997

Audience: 18 representatives from SAF, private industry, and the university

Organized by: Soil Science Department, University of Saskatchewan

Presented by: D. Pennock and F. Walley

Title: Conservation Learning Centre Field Day

Date: July 24, 1997

Audience: approximately 25 producers and agriculture industry representatives and SSCA field staff

Organized by: Conservation Learning Centre

Presented by: D. Pennock

Title: Swift Current Field Day

Date: July 9, 1998

Audience: 275 producers and agriculture industry representatives

Organized by: SPARC, SSCA, and the Wheatlands Conservation Area

Presented by: M. Solohub

Title: Conservation Learning Centre Field Day

Date: July 19, 1998

Audience: approximately 25 producers and agriculture industry representatives and SSCA field staff

Organized by: Conservation Learning Centre

Presented by: M. Solohub

Workshops and Extension Meetings

Title: What Happens to Soil Properties Across the Field; Farming Systems Workshop

Location: Prince Albert, SK.

Date: March 13, 1997

Audience: 100 producers and agriculture industry representatives

Organized by: Conservation Learning Centre

Presented by: F. Walley

Title: Precision Farming Workshop; Precision Farming Regional Extension Team Workshop

Location: Saskatoon, SK.

Date: June 3, 1997

Audience: 28 SAF and SSCA field staff

Organized by: SAF and SSCA

Presented by: D. Pennock and F. Walley

Title: Western Canada Agronomy Workshop

Location: Saskatoon, SK.

Date: July 11, 1997

Topic: "Soil Landscape Characteristics as Related to Precision Farming"

Audience: approximately 400 agriculture industry representatives

Organized by: Canadian Fertilizer Institute

Presented by: F. Walley

Title: Presentation of Results and Extension Materials; Workshop College of Agriculture, U of S

Location: Saskatoon, SK.

Date: November 19, 1997

Audience: 14 SAF and SSCA staff

Organized by: D. Pennock and F. Walley

Presented by: D. Pennock and F. Walley

Title: Soil Landscape and Crop Reaction and Recent Results in Precision Farming

Location: Saskatoon, SK.

Date: November 25, 1997

Audience: 43 producers and dealers

Organized by: SAF Extension Services and SSCA

Presented by: F. Walley

Title: Soil Landscape and Crop Reaction and Recent Results in Precision Farming

Location: Outlook, SK.

Date: November 26, 1997

Audience: 38 producers and dealers, 15 visiting Chinese researchers

Organized by: SAF Extension Services and SSCA

Presented by: D. Pennock

Title: Potential for Precision Farming in Saskatchewan; College Seminar series,
College of Agriculture

Location: Saskatoon, SK.

Date: January 23, 1998

Audience: 90+ faculty, Students, and Researchers

Organized by: College of Agriculture

Presented by: D. Pennock

Title: Variable Rate Fertilizer Application Research Summary

Location: Saskatoon, SK.

Date: February 5, 1998

Topic: Presentation of first year results and implications

Audience: 100 producers and dealers

Organized by: Larry Gramiuk, SAF Extension Services

Presented by: D. Pennock

Title: Precision Farming Overview; 1998 Direct Seeding Conference

Location: Regina, SK.

Date: February 5, 1998

Audience: 1400 registrants

Organized by: Saskatchewan Soil Conservation Association

Presented by: D. Pennock

Title: Developing Precision Farming Strategies; Soils and Crops Workshop, 1998

Location: Saskatoon, SK.

Date: February 20, 1998

Audience: 200 registrants

Organized by: Soils and Crops Workshop Committee, Extension Division (U of S)

Presented by: D. Pennock

Title: Variable Rate Fertilizer Application in a Thin Black Soil; Soils and Crops Workshop, 1998

Location: Saskatoon, SK.

Date: February 20, 1998

Audience: 200 registrants

Organized by: Soils and Crops Workshop Committee, Extension Division (U of S)

Presented by: F. Walley

Title: N Availability Across Different Landscape Positions; Soils and Crops Workshop, 1998

Location: Saskatoon, SK.

Date: February 20, 1998

Audience: 200 registrants

Organized by: Soils and Crops Workshop Committee, Extension Division (U of S)

Presented by: M. Solohub

Title: Optimizing Fertilizer and Seeding Rates for Rolling Landscapes; Brown Soil Zone; Soils and Crops Workshop, 1998

Location: Saskatoon, SK.

Date: February 20, 1998

Audience: 200 registrants

Organized by: Soils and Crops Workshop Committee, Extension Division (U of S)

Presented by: B. McConkey

Title: Influence of Seeding Rate and KCL Application Across the Landscape; Soils and Crops Workshop, 1998

Location: Saskatoon, SK.

Date: February 20, 1998

Audience: 200 registrants

Organized by: Soils and Crops Workshop Committee, Extension Division (U of S)

Presented by: A. Johnston

Title: Precision Farming Basics; Agronomy Training Workshop

Location: Saskatoon, SK.

Date: March 20, 1998

Audience: 132 registrants

Organized by: Extension Division (U of S)

Presented by: D. Pennock

Title: Factors Influencing Crop Production; Writing Workshop for Teachers

Location: Saskatoon, SK.

Date: July 6, 1998

Audience: 10 Public School Teachers

Organized by: Agriculture in the Classroom Inc.

Presented by: F. Walley

Title: Variable Rate Fertilizer Application – Will it Work for You?; Wheat Pool
Open House

Location: Saskatoon, SK.

Date: July 13, 1998

Audience: 25 producers

Organized by: Saskatchewan Wheat Pool, Product Development

Presented by: F. Walley

Title: The Spatial Distribution of Mineralizable N and Related Soil Properties; Soils and Crops Workshop, 1999

Location: Saskatoon, SK.

Date: February 25, 1999

Audience: 200 registrants

Organized by: Soils and Crops Workshop, Extension Division (U of S)

Presented by: T. Yates

Title: Three Years of Precision Farming Research at Hepburn, SK.; Soils and Crops Workshop, 1999

Location: Saskatoon, SK.

Date: February 25, 1999

Audience: 200 registrants

Organized by: Soils and Crops Workshop, Extension Division (U of S)

Presented by: F. Walley

Title: Mineral Nitrogen Variability Across and Within Landscape Positions; Soils and Crops Workshop, 1999

Location: Saskatoon, SK.

Date: February 25, 1999

Audience: 200 registrants

Organized by: Soils and Crops Workshop Committee, Extension Division (U of S)

Presented by: M. Solohub

Title: Developments in Variable Rate Fertilizer Application; Soil Fertility Seminar

Location: Saskatoon, SK.

Date: March 9, 1999

Audience: 50 producers

Organized by: SAF Extension Service

Presented by: F. Walley

Title: Precision Farming - Variable Rate Fertilizer Application; Farmer Agronomy School

Location: Swift Current, SK.

Date: March 10, 1999

Audience: 150 producers

Organized by: Pioneer Co-op Agro Centre

Presented by: F. Walley

Title: Precision Farming – Putting the Pieces of the Puzzle Together; 2000 Industry Update

Location: Saskatoon, SK.

Date: January 27, 2000

Audience: 84 registrants

Organized by: Saskatchewan Agriculture and Food, Extension Services.

Presented by: F. Walley

Title: Precision Farming – Precisely What do We Know?; 2000 SSCA Direct Seeding Conference

Location: Regina, SK.

Date: February 9, 2000

Audience: 700 producers

Organized by: Saskatchewan Soil Conservation Association

Presented by: F. Walley

Title: Summary of Precision Farming Research at the University of Saskatchewan; Soils and Crops Workshop, 2000

Location: Saskatoon, SK.

Date: February 24, 2000

Audience: 200 registrants

Organized by: Soils and Crops Workshop Committee, Extension Division (U of S)

Presented by: D. Pennock

Title: Agronomic and Economic Assessment of VRF in Saskatchewan; Great Plains
Soil Fertility Conference, 2000

Location: Denver CO, USA

Date: March 7, 2000

Audience: 150 researchers and Industry personnel

Organized by: Potash and Phosphate Institute

Presented by: F. Walley

GIS Workshops

Title: GIS in Agriculture Workshops (3)

Location: University of Saskatchewan

Dates: March 16-17, 1999

March 18-19, 1999

March 23-24, 1999

Audience: 10 participants/workshop

Organized by: Extension Division (U of S)

Presented by: D. Pennock, D. Elliot, A. Frick, and F. Walley

(c) PERSONNEL

Staff member	Title	Employment Duration	Approx. salary (\$/month)
M. Solohub	Research Officer	Entire project (¾ time)	3500
R. Anderson	Technical Assistant	Entire project (¾ time)	2700
Q. Chen	Laboratory Technician	May 1, 1998 – Nov. 31, 1999	1700
D. Elliott	Research Officer	Dec 1 – Mar. 31, 1998	2500
C. Wiebe	Research Technician	Dec. 1 – Mar. 31, 1998	1600
A. Bedard-Haughn	Research Technician	Jul. 1- Aug. 31, 1999	2500
K. McLean	M.Sc. student (Ag Ec)	May – Oct., 1999	1925
S Blechinger	Summer Student	May 1 – Aug. 31, 1997	1600
M. Dyck	Summer Student	May 1 – Aug. 31, 1998	1600
R. Farkas	Summer Student	Oct. 1 – Mar. 31, 1998	1700
D. Adderley	Summer Student	Aug. 15 – Aug. 31, 1998	1600
A. Wilson	Summer Student	Aug. 15 – Aug. 31, 1998	1600
C. Karwecki	Summer Student	May 1 – Aug. 31, 1999	1600
M.Backx	Exchange Student	Apr. 15 – Sept. 15, 1999	1600

(d) EQUIPMENT RENTAL

Four Campbell Scientific Meteorological Stations were leased from the Department of Soil Science, University of Saskatchewan for the duration of the project.

Each station includes:

- 1: CR10X Measurement and control Module w/ 128K RAM memory
- 1: Fiberglass Enclosure
- 2: T107 Temperature Probes (Soil and Air)
- 1: Texas Electronics Tipping bucket Rain Gauge

These systems were leased at a cost of \$1022 per station per year from the Department.

(e) PROJECT PHOTOS

A number of photographs of the experimental sites were taken during the course of this study. These photos are available upon request.

(f) INNOVATION FUND ACKNOWLEDGEMENT

The financial support of the Agri-Food innovation Fund was acknowledged at all extension activities and has been included in all written documents related to this study.

(g) PROJECT PUBLIC INFORMATION MATERIALS

Appended (Appendix 1)

(h) EXPENSE STATEMENT

To be provided by the University of Saskatchewan.